UN environment

United Nations Environment Programme

# GLOBAL CHEMICALS OUTLOOK II

## FROM LEGACIES TO INNOVATIVE SOLUTIONS

### IMPLEMENTING THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT

**Global Chemicals Outlook II**

*From Legacies to Innovative Solutions: Implementing the 2030 Agenda for Sustainable Development*



ISBN No: 978-92-807-3745-5
Job No: DTI/2230/GE

**Feedback and contact**

The United Nations Environment Programme encourages interested readers of this report to engage and become part of the Global Chemicals Outlook II community. We are keen to hear your views about the report and how it makes a difference on the ground.

Please contact: science.chemicals@un.org

Cover photo:
© Bannafarsai_Stock/Shutterstock

UNEP promotes environmentally sound practices globally and in its own activities. This publication will be available as an electronic document. Our distribution policy aims to reduce UNEP's carbon footprint.

# About the Global Chemicals Outlook II

The first edition of the *Global Chemicals Outlook*, published in February 2013, assembled scientific, technical and socio-economic information on the sound management of chemicals. It covered trends and indicators for chemical production, transport, use and disposal, and associated health and environmental impacts; economic implications of these trends, including costs of inaction and benefits of action; and instruments and approaches for sound management of chemicals.

Decision 27/12, adopted by the Governing Council of the United Nations Environment Programme in 2013, recognized the significance of the findings of the first *Global Chemicals Outlook*, which highlighted the significant increase in the manufacture and use of chemicals globally, their importance to national and global economies and the costs and negative effects on human health and the environment of unsound chemicals management, and made recommendations for future action. Decision 27/12 also requested the Executive Director to continue work on the *Global Chemicals Outlook*, particularly in areas where data were found to be lacking or inadequate, and to enhance transparency through regionally balanced stakeholder involvement, inter alia, with a view to developing in the future a tool for assessing progress towards the achievement of the sound management of chemicals and hazardous wastes, including the existing 2020 goal, taking into account and building upon other existing sources of information.

Resolution 2/7, adopted by the United Nations Environment Assembly in 2016, requested the Executive Director to submit an update of the first *Global Chemicals Outlook*, addressing, inter alia, the work carried out particularly in relation to lacking or inadequate data to assess progress towards the 2020 goal, the development of non-chemical alternatives, and the linkages between chemicals and waste, in coordination with the *Global Waste Management Outlook*, and providing scientific input and options for implementation of actions to reach relevant Sustainable Development Goals and targets up to and beyond 2020. Resolution 2/7 also requested the Executive Director to ensure that the updated *Global Chemicals Outlook* addresses the issues which have been identified as emerging policy issues by the International Conference on Chemicals Management (the governing body of the Strategic Approach to International Chemicals Management) as well as other issues where emerging evidence indicates a risk to human health and the environment.

The second edition of the *Global Chemicals Outlook* has been prepared with substantive contributions from more than 400 experts and under the guidance of a Steering Committee, which provided oversight, strategic directions and guidance on all aspects of the report's development, as well as technical inputs, where applicable. The Steering Committee was composed of representatives from Governments, non-governmental organizations (including civil society, industry/the private sector, and academia) and inter-governmental organizations, with participation from all regions and a wide range of stakeholders.

UN environment assembly

The *Global Chemicals Outlook II* is complemented by the *Global Chemicals Outlook II Summary for Policymakers* and the *Global Chemicals Outlook II Synthesis Report*. The *Synthesis Report* summarizes key findings and insights of the full report and follows the same five-part structure. It was launched at the fourth session of the United Nations Environment Assembly in March 2019. The shorter *Summary for Policymakers* was tabled as a working document of the fourth session of the United Nations Environment Assembly and is available in all six UN languages.

# Acknowledgements

The *Global Chemicals Outlook II* has been developed through substantive input from a wide range of experts, and through collaboration with numerous partner organizations. The United Nations Environment Programme wishes to thank all individuals and organizations that have generously contributed their expertise, time, and energy.

The Steering Committee provided oversight, strategic direction, guidance and technical inputs throughout the process. The members of the Committee were: Keith Alverson, Ingela Andersson, Heidar Ali Balouji, Ricardo Barra, Andrea Brown, Leticia Carvalho, Emma Chynoweth, Bob Diderich, Joe DiGangi, Szymon Domagalski, Jutta Emig, Richard Fuller, Veronique Garny, Fernando Gomez, Florencia Grimalt, Björn Hansen, Juergen Helbig, Sverre Thomas Jahre, David Kapindula, Brenda Koekkoek, Brian Kohler, Kouame Georges Kouadio, Klaus Kümmerer, Mungath Kutty, Vladimir Lenev, Suzanne Leppinen, Jianguo Liu, Christoph Neumann, Jorge Ocaña, Hanna-Andrea Rother, Tatiana Santos, Claudia ten Have, Baskut Tuncak, Carolyn Vickers, Melissa Mengjiao Wang, Katherine Weber, Felix Wertli, Susan Wilburn, and Kei Ohno Woodall. Back-up support to members of the Committee was provided by, among others, Angelina Buchar, Tracey Easthope, Manoj Kumar Gangeya, Vassilios Karavezyris, Sunday Leonard, Eugeniy Lobanov, Andrew McCartor, Geraint Roberts, Dolores Romano, Leigh Stringer, Michel Tschirren, Victoria Tunstall, and Carla Valle-Klann.

Lead authors responsible for the drafting of foundational papers and specific chapters were: Francisco Alpizar, Thomas Backhaus, Nils Decker, Ingo Eilks, Natalia Escobar-Pemberthy, Peter Fantke, Ken Geiser, Maria Ivanova, Olivier Jolliet, Ho-seok Kim, Kelvin Khisa, Haripriya Gundimeda, Daniel Slunge, Stephen Stec, Joel Tickner, David Tyrer, Niko Urho, Rob Visser, Mario Yarto, and Vania Gomes Zuin. Ken Geiser served as coordinating author for Part I. Rob Visser served as coordinating author for Parts II and III. Lead authors for capturing regional perspectives were Babajide Alo, Vera Barrantes,

© UNEP

Li Jinhui, Anna Makarova, and Chen Yuan, with further input provided by Mohamed Abdelraouf, Svein Rasmussen, Jeff Seadon, Noriyuki Suzuki, Le Viet Thang, and Htwe Win.

Further substantive contributions were provided by: Katinka De Balogh, Marie-Ange Baucher, Richard Blume, Rafael Cayuela, Maria Delfina Cuglievan, Heidelore Fiedler, John Haines, Lei Huang, Nicole Illner, Molly Jacobs LeFevre, Edwin Janssen, Elisabeth Krausmann, Nyree Bekarian Mack, Rachel Massey, Frank Moser, Amos Necci, Ieva Rucevska, David Sutherland, Urvi Talaty, Dirk Uhlemann, Elze van Hamelen, Willem van Lanschot, Melissa Mengjiao Wang, Zhanyun Wang, Maureen Wood, Oliver Wootton, and Evetta Zenina.

A Consultative Meeting for the Preparation of the *Global Chemicals Outlook II* took place in April 2016 in Geneva, Switzerland. It was attended by 70 experts. Subsequently a wide range of stakeholders provided input at five workshops. These consisted of a series of regional expert workshops in March-April 2018 in Nairobi, Kenya (Africa); Frankfurt, Germany (Europe, including Central and Eastern Europe); Panama City, Panama (Latin America and the Caribbean and North America); and Bangkok, Thailand (Asia-Pacific and West Asia), attended by a total of 115 participants; and a global workshop (June 2018, Bonn, Germany) with some 100 participants. Paul Hohnen provided valuable support, including by moderating sessions at several workshops.

Independent experts, identified based on nominations received from the Scientific and Technical Advisory Panel of the Global Environment Facility, the secretariat supporting the preparation of UNEP Environment's sixth *Global Environment Outlook*, and the International Solid Waste Association, were invited to review the draft GCO-II. In addition, external experts were invited to review selected sections based on their expertise. The following individuals provided valuable feedback: Marlene Agerstrand, Tom Bond, Weihsueh Chiu, Victoria de Higa, Paul Dumble, Henning Friege, Martin Führ, Sarah Green, Jamidu Katima, Sayed Khattari, Joy Aeree Kim, Olwenn Martin, Ackmez Mudhoo, Carlos Ocampo Lopez, Stephen Macey, Prasad Modak, Naglaa Mohamed Loutfy, Jennifer McKellar, Percy Onianwa, Kamlesh Pathak, Andreas Prevodnik, Alexander Romanov, Mark Rossi, Ted Smith, Gustavo Solorzano, Gerard Swaen, Mohamed Tawfic, Zijian Wang, and Meriel Watts.

Various organizations provided contributions to the development of the *Global Chemicals Outlook II*. The International Sustainable Chemistry Collaborative Centre (ISC3) (overall lead: Friedrich Barth; supported by Alexis Bazzanella, Nils Decker, Agnes Dittmar, Silke Megelski and Brigitta Meier) provided support in co-organizing the four regional workshops and the global workshop, as well as substantive contributions on megatrends and industry sectors. The International Panel on Chemical Pollution (overall leads: Martin Scheringer, Justin Boucher and Zhanyun Wang; supported by Thuy Bui, Dämien Bolinius, Elsemieke de Boer, Miriam Diamond, Patrick FitzGerald, Adelene Lai, Grégoire Meylan, Amélie Ritscher, Thomas Roiss, Christina Rudén, and Iona Summerson) undertook background research and prepared a foundational paper addressing the emerging policy issues and other issues of concern. The United Nations Institute for Training and Research (overall lead: Jorge Ocana; supported by Oliver Wootton and Ester Hermosilla) assisted by co-organizing meetings and workshops, as well as by facilitating delivery of substantive contributions.

The following entities provided comments and in-kind contributions throughout the process: the Inter-Organization Programme for the Sound Management of Chemicals participating organizations (Food and Agriculture Organization of the United Nations, International Labour Organization, United Nations Development Programme, United Nations Environment Programme, United Nations Industrial Development Organization, United Nations Institute for Training and Research, World Health Organization, World Bank, Organisation for Economic Co-operation and Development), the Secretariat of the Basel, Rotterdam and Stockholm Conventions, the Secretariat of the Minamata Convention, the Secretariat for the Vienna Convention and its Montreal Protocol

(Ozone Secretariat) and the Secretariat for the Multilateral Fund for the Implementation of the Montreal Protocol, the Secretariat of the Strategic Approach to International Chemicals Management (SAICM), Chemical Watch, The Natural Step, Statista, and the World Economic Forum.

The *Global Chemicals Outlook II* was prepared by the United Nations Environment Programme, Economy Division, Chemicals and Health Branch, and coordinated and edited by Achim Halpaap with Jost Dittkrist. Further valuable guidance, input and contributions have been provided by Jacqueline Alvarez, Abdouraman Bary, Llorenç Mila Canals, Kenneth Davis, Jacob Duer, Tessa Goverse, Mijke Hertoghs, Adam Hodge, Tim Kasten, Stephanie Laruelle, Isabelle Louis, Kaj Madsen, Imae Mojado, Kakuko Nagatani-Yoshida, Desiree Raquel Narvaez, Ligia Noronha, Jordi Pon, Pierre Quiblier, Liazzat Rabbiosi, Victor Hugo Estellano Schulze, Nalini Sharma, Ying Su, Eisaku Toda, Elisa Tonda, Eloise Touni, and numerous other colleagues. Administrative and other support has been provided by Erika Mattsson, Panos Kalogirou, Scholastica Theuri, Pascale Unger and Leila Younossi. Editing support has been provided by John Smith, graphic design and layout by Lowil Espada, with the support of Fabrice Clavien and Elsemieke de Boer, and referencing and data management support by Tapiwa Nxele.

Generous financial and in-kind contributions to develop the *Global Chemicals Outlook II* have been provided by the European Union and the Governments of Denmark, Germany, Norway, Sweden, and Switzerland.

# Foreword

Chemicals are part of our everyday lives. From pharmaceuticals to plant protection, innovations in chemistry can improve our health, food security and much more. However, if poorly used and managed, hazardous chemicals and waste threaten human health and the environment.

As the second *Global Chemicals Outlook* lays out, global trends such as population dynamics, urbanization and economic growth are rapidly increasing chemical use, particularly in emerging economies. In 2017, the industry was worth more than US dollars 5 trillion. By 2030, this will double. Whether this growth becomes a net positive or a net negative for humanity depends on how we manage the chemicals challenge. What is clear is that we must do much more.

Large quantities of hazardous chemicals and pollutants continue to leak into the environment, contaminating food chains and accumulating in our bodies, where they do serious damage. Estimates by the European Environment Agency suggest that 62 per cent of the volume of chemicals consumed in Europe in 2016 were hazardous to health. The World Health Organization estimates the burden of disease from selected chemicals at 1.6 million lives in 2016. The lives of many more are negatively impacted.

We have made some progress in managing chemicals through national and stakeholder action, international treaties and voluntary instruments. At the World Summit on Sustainable Development in 2002, countries committed to minimizing the adverse effects of chemicals by 2020. At our current pace, we will not achieve this goal. Considering the expansion of the market, and the associated increase in contamination, we cannot continue to gamble with our health.

Solutions do exist, as the report shows. Sustainable supply chain management, innovations in green and sustainable chemistry, and adopting common approaches to chemicals management can reduce the risks to human health, ecosystems and economies. But a solution is only as good as the will to implement it. Now, more than ever, key influencers such as investors, producers, retailers, citizens, academics and ministers must act. We have the chance to do what needs to be done. We are implementing the 2030 Agenda and developing a future framework for framework for the sound management of chemicals and waste beyond 2020.

We cannot live without chemicals. Nor can we live with the consequences of their bad management. My hope is that this Outlook inspires us all to increase our efforts to safely capture the benefits of chemistry for all humanity.

Joyce Msuya
Acting Executive Director
UN Environment

# Key findings

**The global goal to minimize adverse impacts of chemicals and waste will not be achieved by 2020. Solutions exist, but more ambitious worldwide action by all stakeholders is urgently required.**

1. The size of the global chemical industry exceeded United States dollars 5 trillion in 2017. It is projected to double by 2030. Consumption and production are rapidly increasing in emerging economies. Global supply chains, and the trade of chemicals and products, are becoming increasingly complex.

2. Driven by global megatrends, growth in chemical-intensive industry sectors (e.g. construction, agriculture, electronics) creates risks, but also opportunities to advance sustainable consumption, production and product innovation.

3. Hazardous chemicals and other pollutants (e.g. plastic waste and pharmaceutical pollutants) continue to be released in large quantities. They are ubiquitous in humans and the environment and are accumulating in material stocks and products, highlighting the need to avoid future legacies through sustainable materials management and circular business models.

4. The benefits of action to minimize adverse impacts have been estimated in the high tens of billions of United States dollars annually. The World Health Organization estimated the burden of disease from selected chemicals at 1.6 million lives in 2016 (this is likely to be an underestimate). Chemical pollution also threatens a range of ecosystem services.

5. International treaties and voluntary instruments have reduced the risks of some chemicals and wastes, but progress has been uneven and implementation gaps remain. As of 2018, more than 120 countries had not implemented the Globally Harmonized System of Classification and Labelling of Chemicals.

6. Addressing legislation and capacity gaps in developing countries and emerging economies remains a priority. Also, resources have not matched needs. There are opportunities for new and innovative financing (e.g. through cost recovery and engagement of the financial sector).

7. Significant resources can be saved by sharing knowledge on chemical management instruments more widely, and by enhancing mutual acceptance of approaches in areas ranging from chemical hazard assessment to alternatives assessment.

8. Frontrunner companies – from chemical producers to retailers – are introducing sustainable supply chain management, full material disclosure, risk reduction beyond compliance, and human rights-based policies. However, widespread implementation of these initiatives has not yet been achieved.

9. Consumer demand, as well as green and sustainable chemistry education and innovation (e.g. though start-ups), are among the important drivers of change. They can be scaled up through enabling policies, reaping the potential benefits of chemistry innovations for sustainable development.

10. Global knowledge gaps can be filled. This can be achieved, for example, by taking steps to harmonize research protocols, considering health or environmental impact information and harm caused to set and address priorities (e.g. emerging issues), and strengthening the science-policy interface through enhanced collaboration of scientists and decision-makers.

# List of Abbreviations and Acronyms

| | |
|---|---|
| **ACC** | American Chemistry Council |
| **ACS** | American Chemical Society |
| **AMAP** | Arctic Monitoring and Assessment Programme |
| **AMR** | Antimicrobial resistance |
| **AOP** | Adverse Outcome Pathway |
| **ASBC** | American Sustainable Business Council |
| **ASGM** | Artisanal and small-scale gold mining |
| **BCG** | Boston Consulting Group |
| **BHRRC** | Business and Human Rights Resource Centre |
| **BPA** | Bisphenol A |
| **BPS** | Bisphenol S |
| **BRS** | Basel, Rotterdam and Stockholm |
| **CAGR** | Compound annual growth rate |
| **CAPP** | Chemical Accident Prevention and Preparedness |
| **CEE** | Central and Eastern Europe |
| **Cefic** | European Chemical Industry Council |
| **CFC-11** | Trichlorofluoromethane |
| **CFCs** | Chlorofluorocarbons |
| **CiP** | Chemicals in Products |
| **CIRS** | Chemical Inspection and Regulation Service |
| **CLP** | Classification, Labelling and Packaging |
| **CMR** | Carcinogenic, mutagenic and reprotoxic |
| **CMS** | Chemical management services |
| **$CO_2$** | Carbon dioxide |
| **$CO_2$-eq** | Carbon dioxide equivalent |
| **COP** | Conference of the Parties |
| **DALYs** | Disability-adjusted life years |
| **DDT** | Dichlorodiphenyltrichloroethane |
| **DEHP** | Bis(2-ethylhexyl) phthalate |
| **EC** | European Commission |
| **ECHA** | European Chemicals Agency |
| **EDCs** | Endocrine-disrupting chemicals |
| **EEA** | European Environment Agency |
| **EFPIA** | European Federation of Pharmaceutical Industries and Associations |
| **EFSA** | European Food Safety Authority |
| **EHS** | Environment, health and safety |
| **EIPs** | Eco-industrial parks |
| **eMARS** | EU Major Accident Reporting System |
| **EPIs** | Emerging policy issues |
| **EPPP** | Environmentally persistent pharmaceutical pollutants |
| **ESDs** | Emission Scenario Documents |
| **EU** | European Union |
| **EWG** | Environmental Working Group |
| **EY** | Ernst & Young |
| **FAO** | Food and Agriculture Organization of the United Nations |
| **GAHP** | Global Alliance on Health and Pollution |

| | |
|---|---|
| **GC3** | Green Chemistry & Commerce Council |
| **GCO-I** | First Global Chemicals Outlook |
| **GCO-II** | Second Global Chemicals Outlook |
| **GDP** | Gross domestic product |
| **GEF** | Global Environment Facility |
| **GHG** | Greenhouse gas |
| **GHS** | Globally Harmonized System of Classification and Labelling of Chemicals |
| **GPA** | SAICM Global Plan of Action |
| **GRI** | Global Reporting Initiative |
| **GRULAC** | Group of Latin American and Caribbean Countries |
| **GSCE** | Green and sustainable chemistry education |
| **HCFCs** | Hydrochlorofluorocarbons |
| **HDI** | Human Development Index |
| **HFCs** | Hydrofluorocarbons |
| **HHPs** | Highly hazardous pesticides |
| **HRC** | Human Rights Council |
| **HSLEEP** | Hazardous substances within the life cycle of electrical and electronic products |
| **IARC** | International Agency for Research on Cancer |
| **ICCA** | International Council of Chemical Associations |
| **ICCM** | International Conference on Chemicals Management |
| **IEA** | International Energy Agency |
| **IFIC** | International Food Information Council |
| **IFPMA** | International Federation of Pharmaceutical Manufacturers and Associations |
| **IGO** | Intergovernmental organization |
| **IHR** | WHO International Health Regulations |
| **ILO** | International Labour Organization |
| **ILZSG** | International Lead and Zinc Study Group |
| **IOMC** | Inter-Organization Programme for the Sound Management of Chemicals |
| **IP** | Intellectual property |
| **IPEN** | International POPs Elimination Network |
| **IPM** | Integrated Pest Management |
| **ISO** | International Organization for Standardization |
| **ISWA** | International Solid Waste Association |
| **IT** | Information technology |
| **IUPAC** | International Union of Pure and Applied Chemistry |
| **JPOI** | Johannesburg Plan of Implementation |
| **KEMI** | Swedish Chemicals Agency |
| **LAC** | Latin America and the Caribbean |
| **LCA** | Life cycle assessment |
| **LMICs** | Low- and middle-income countries |
| **MEA** | Multilateral environmental agreement |
| **Mt** | Megatonne |
| **NAFTA** | North American Free Trade Agreement |
| **Natech** | Natural hazard triggered technological (accident) |
| **ng** | Nanogram |
| **NGO** | Non-governmental organization |

| | |
|---|---|
| **ODS** | Ozone-depleting substance |
| **OECD** | Organisation for Economic Cooperation and Development |
| **OHS** | Occupational Health and Safety |
| **OOG** | SAICM Overall Orientation and Guidance |
| **OPS** | SAICM Overarching Policy Strategy |
| **PAHs** | Polycyclic aromatic hydrocarbons |
| **PAN** | Pesticide Action Network |
| **PBDEs** | Polybrominated diphenyl ethers |
| **PBT** | Persistent, bioaccumulative and toxic |
| **PCBs** | Polychlorinated biphenyls |
| **PCDDs** | Polychlorinated dibenzo-p-dioxins |
| **PCDFs** | Polychlorinated dibenzofurans |
| **PE** | Polyethylene |
| **PET** | Polyethylene terephthalate |
| **PFASs** | Per- and polyfluoroalkyl substances |
| **PFCs** | Perfluorinated chemicals |
| **PFDA** | Nonadecafluorodecanoic acid |
| **PFHxS** | Perfluorohexanesulfonic acid |
| **PFNA** | Perfluorononanoic acid |
| **PFOA** | Perfluorooctanoic acid |
| **PFOS** | Perfluorooctanesulfonic acid |
| **PFRs** | Organophosphate-based flame retardants |
| **pg** | Picogram |
| **PHAs** | Polyhydroxyalkanoates |
| **PLA** | Polylactic acid |
| **POPs** | Persistent organic pollutants |
| **PPE** | Personal protective equipment |
| **PRTRs** | Pollutant Release and Transfer Registers |
| **PTFE** | Polytetrafluoroethylene |
| **PV** | Photovoltaic |
| **PVC** | Polyvinyl chloride |
| **PwC** | PricewaterhouseCoopers |
| **QSP** | SAICM Quick Start Programme |
| **R&D** | Research and development |
| **REACH** | Registration, Evaluation, Authorization and Restriction of Chemicals |
| **Rio+20** | United Nations Conference on Sustainable Development |
| **RSC** | Royal Society of Chemistry |
| **SAICM** | Strategic Approach to International Chemicals Management |
| **SDGs** | Sustainable Development Goals |
| **SDS** | Safety data sheet(s) |
| **SEA** | Socio-economic assessment |
| **SEI** | Stockholm Environment Institute |
| **SMEs** | Small and medium-sized enterprises |
| **SVHC** | Substances of very high concern |
| **TCE** | Trichloroethylene |
| **TRI** | United States Toxics Release Inventory |
| **TSCA** | United States Toxic Substances Control Act |
| **UBA** | German Environment Agency |
| **UK** | United Kingdom |
| **UN** | United Nations |
| **UNCED** | United Nations Conference on Environment and Development |

**UN DESA** United Nations Department of Economic and Social Affairs

**UNDP** United Nations Development Programme

**UNEA** United Nations Environment Assembly of the United Nations Environment Programme

**UNECE** United Nations Economic Commission for Europe

**UNEP** United Nations Environment Programme

**UNESCO** United Nations Educational, Scientific and Cultural Organization

**UNIDO** United Nations Industrial Development Organization

**UNISDR** United Nations Office for Disaster Relief Reduction

**UNITAR** United Nations Institute for Training and Research

**UNRISD** United Nations Research Institute for Social Development

**US/USA** United States

**US ATSDR** United States Agency for Toxic Substances and Disease Registry

**US CDC** United States Centers for Disease Control and Prevention

**US EPA** United States Environmental Protection Agency

**US FDA** United States Food and Drug Administration

**US GAO** United States Government Accountability Office

**USGS** United States Geological Survey

**US NASEM** United States Academies of Science, Engineering and Medicine

**US NHANES** United States National Health and Nutrition Examination Survey

**US NOAA** United States National Oceanic and Atmospheric Administration

**US NRC** United States National Research Council

**US NTP** United States National Toxlcology Program

**US OSHA** United States Occcupational Safety and Health Administration

**VCI** German Chemical Industry Association

**VOCs** Volatile organic compounds

**WBCSD** World Business Council for Sustainable Development

**WECF** Women in Europe for a Common Future/Women Engage for a Common Future

**WEEE** Waste electrical and electronic equipment

**WEF** World Economic Forum

**WEOG** Western European and Others Group

**WIPO** World Intellectual Property Organization

**WHO** World Health Organization

**WMO** World Meteorological Organization

**WSSD** World Summit on Sustainable Development

**ZDHC** Zero Discharge of Hazardous Chemicals

# Contents

**Introduction: chemicals and waste in the broader sustainable development context** xxxii

1/ The global context for the sound management of chemicals and waste 2

2/ Milestones in international chemicals and waste management 5

3/ Opportunities to link international policy agendas 10

4/ Overview of the Global Chemicals Outlook II 14

References 15

**Key messages for policymakers: a call for more ambitious action at all levels** 16

**I. The evolving chemicals economy: status and trends relevant for sustainability** 22

1/ The chemical industry 24

2/ Trends in production and sales of specific chemicals 41

3/ Megatrends and chemical-intensive industry sectors: risks and opportunities 61

4/ Global supply chains, chemicals in products, and circularity 78

5/ Chemical pollution: emissions, releases and wastes 92

6/ Concentrations of chemicals in the environment and humans 120

7/ Environmental, health and social effects of chemicals 145

8/ The economic benefits of action and the costs of inaction 164

References 176

II. **Where do we stand in achieving the 2020 goal – assessing overall progress and gaps** 218

1/ International agreements and frameworks on chemicals and waste 220

2/ Reporting schemes and indicators under international agreements and frameworks 228

3/ Achieving the 2020 goal: what do we know? 241

4/ Emerging policy issues and other issues of concern 291

5/ Other issues where emerging evidence indicates a risk 320

6/ Overall progress towards the 2020 goal: what have we learned? 330

Annex: Other issues where emerging evidence indicates a risk 335

References 347

III. **Advancing and sharing chemicals management tools and approaches: taking stock, looking into the future** 382

1/ Hazard assessment: progress in information generation and hazard characterization 384

2/ Exposure assessment: benefiting from internationally available resources 396

3/ Risk assessment: opportunities to improve and accelerate progress 406

4/ Risk management decision-making: making it work in all countries 419

5/ Assessment of chemical and non-chemical alternatives: focusing on solutions 435

6/ Chemical risk management in facilities and during production 453

7/ Approaches to sustainability assessment 468

References 474

## IV. Enabling policies and action to support innovative solutions 502

1/ Envisioning and shaping the future of chemistry 504

2/ Green and sustainable chemistry education: nurturing a new generation of chemists 515

3/ Strengthening sustainable chemistry technology innovation and financing 524

4/ Evolving and new business models 542

5/ Fiscal incentives to advance sound chemicals management and sustainable chemistry 555

6/ Sustainable supply chain management for chemicals and waste in the life cycle 564

7/ Sustainability metrics and reporting: measuring progress, strengthening accountability 575

8/ Empowering and protecting citizens, workers and consumers 586

References 604

## V. Scaling up collaborative action under the 2030 Agenda for Sustainable Development 628

1/ The 2030 Agenda for Sustainable Development: an integrated framework for action 630

2/ Strengthening collaborative action on chemicals and waste in line with the 2030 Agenda 641

3/ Engaging all sectors and actors in chemicals and waste management beyond 2020 651

References 655

## Index 658

# List of Figures

## Introduction: chemicals and waste in the broader sustainable development context

### 1/ The global context for the sound management of chemicals and waste


Figure 1.1 Share of the volume of chemicals consumed in the European Union in 2016 by hazard categories 3


### 2/ Milestones in international chemicals and waste management


Figure 2.1 Key milestones in global sustainable development governance (which also included the sound management of chemicals and waste) 6

Figure 2.2 The Sustainable Development Goals 8


### 3/ Opportunities to link international policy agendas


Figure 3.1 The waste hierarchy, sustainable materials management and the circular economy 12


## I. The evolving chemicals economy: status and trends relevant for sustainability

### 1/ The chemical industry


Figure 1.1 Total chemical industry revenues, 2002-2016 (US dollars billion) 25

Figure 1.2 Chemical sales by geographic region, 2017 (EUR billion) 25

Figure 1.3 Growth in production volume, 2000-2017 26

Figure 1.4 Global chemical industry capacity growth in million tonnes, 2000-2017 27

Figure 1.5 Projected growth in world chemical sales, 2017-2030 28

Figure 1.6 Projection of annual production growth in the chemical industry by region, 2015-2022 (per cent change per year) 28

Figure 1.7 Value chain of the chemical industry: from extraction to finished products 29

Figure 1.8 Chemical segments in the global value chain 30

Figure 1.9 Trends in materials extraction, financial value creation and greenhouse gas emissions (1900-2050) 31

Figure 1.10 The global material footprint: extracted resources by key societal needs and consumables, 2015 (billion tonnes) 32

Figure 1.11 Resource extraction by the chemical sector and related chemicals production, 2013 in millions of tonnes (Mt) 33

Figure 1.12 Feedstocks for chemical production, 2000-2040 (quadrillion British thermal units [BTUs]) 34

Figure 1.13 Share of Asian bio-based polymer production capacity in global production, 2016 (per cent) 35

Figure 1.14 International trade associations along the chemical industry value chain 36
Figure 1.15 World chemical industry structure evolution, share of revenue, 2000-2017 37
Figure 1.16 Number and value of corporate acquisitions in the chemical industry, 2008-2017 (US dollars billion) 37
Figure 1.17 Number of completed mergers and acquisitions in the pharmaceutical industry, 1995-2016 38
Figure 1.18 Global chemical mergers and acquisitions activity by target market, 2010-2017 38
Figure 1.19 Corporate research and development spending globally, 2007 and 2017 (EUR billion) 39
Figure 1.20 Number of chemistry-related patents granted by region, 1987-2016 40

## 2/ Trends in production and sales of specific chemicals

Figure 2.1 Global chemical shipments by segment in 2006, 2011 and 2016 (US dollars billion) 42
Figure 2.2 Production of DDT by decade since 1940 44
Figure 2.3 Value of global pesticide trade, 1970-2016 (US dollars billion) 47
Figure 2.4 Global and regional sales of crop protection products in 2015 (US dollars million) 48
Figure 2.5 Worldwide total prescription drug sales (US dollars billion) and growth rate (per cent), 2010-2024 49
Figure 2.6 Geographical breakdown (by main markets) of sales of new medicines launched in the period 2012-2017 49
Figure 2.7 Global flame retardants market by chemistry, 2017 51
Figure 2.8 Global lead consumption by product, 2018 52
Figure 2.9 Global mercury demand by sector, including uncertainties, 2005-2015 (tonnes) 53
Figure 2.10 Asbestos mine production in the largest producer countries, 2010-2017 (tonnes) 57
Figure 2.11 Global and regional plastics production, 1950-2050 (million tonnes) 57
Figure 2.12 Distribution of global plastics production, 2017 (per cent) 58
Figure 2.13 Uses of plastic: main downstream sectors, 2017 (per cent) 59
Figure 2.14 Global bioplastics production capacity, 2017-2023 (thousand tonnes) 60

## 3/ Megatrends and chemical-intensive industry sectors: risks and opportunities

Figure 3.1 Growth of basic chemical production capacity vs. population growth, 1990-2030 63
Figure 3.2 Middle class dominance in 2030 (in billions) 64
Figure 3.3 The growth of e-commerce, 2016-2021 65
Figure 3.4 Growth of the urban population by city size, 1990-2030 67
Figure 3.5 Trends in the number of loss-relevant natural events, 1980-2016 68
Figure 3.6 Global e-waste generated by volume and per inhabitant, 2014-2021 71
Figure 3.7 Use of pesticides per area of cropland, kg/ha, sum 2006-2016 73
Figure 3.8 Global average annual net capacity additions by type of energy (gigawatts), 2010-2016 and 2017-2040 75
Figure 3.9 Growth of clothing sales and comparison with declining clothing utilization 77

## 4/ Global supply chains, chemicals in products, and circularity

Figure 4.1 Illustration of the complexity of global supply chains: the case of an electronic product 79
Figure 4.2 Relative scale of exports of toys from China by importing market 79
Figure 4.3 Global supply chain in the textile sector 80
Figure 4.4 Relationship between global value chains, product life cycles, product supply chains and chemical supply chains in a linear economy 82
Figure 4.5 Chemicals in an office chair 83
Figure 4.6 Variations in chemical content in a body lotion and in vinyl flooring (per cent) 84

Figure 4.7 Simplified material flow of a circular economy in a global scale with health and environmental risks 87
Figure 4.8 Unintended residues found in recyclable waste paper (mg/kg) 87
Figure 4.9 Concept-to-production (C2P) global regulations by subject, cumulative total 89

## 5/ Chemical pollution: emissions, releases and wastes

Figure 5.1 The value chain of the chemical industry, with emissions/releases to the environment 93
Figure 5.2 On-site air releases in the United States reported to the Toxics Release Inventory (TRI), 2006-2016 (million pounds) 95
Figure 5.3 National/regional PCDD/PCDF releases per unit area 97
Figure 5.4 Potential sources of chemical water pollution 98
Figure 5.5 On-site hazardous surface water discharges in the United States reported to the Toxics Release Inventory (TRI) (millions of pounds), 2006-2016 99
Figure 5.6 Global releases of plastic and microplastic waste to oceans (million tonnes per year) 102
Figure 5.7 Average active ingredient application rates over time as a function of the decade of introduction, 1950s-2000s 103
Figure 5.8 Global glyphosate use, 1994-2014 (tonnes) 104
Figure 5.9 Contributors to VOC emissions to ambient air in Los Angeles, California, 2010 106
Figure 5.10 Spatial distribution of releases of linear alkylbenzene sulphonate (LAS) due to household emissions in Asia, in $mg/m^2/day$ 107
Figure 5.11 Waste generation by level of national income (US dollars) 109
Figure 5.12 Composition of municipal solid waste in Sub-Saharan Africa (per cent) 110
Figure 5.13 Recycled and composted waste as a share of total municipal waste in OECD countries (per cent), 2013 111
Figure 5.14 Global hazardous waste generation in 2009 (thousand tonnes) 113
Figure 5.15 Sources of hazardous waste in the United States by sector, 2011 (per cent of volume) 113
Figure 5.16 Sources of hazardous waste in EU countries by sector, 2015 (per cent) 114
Figure 5.17 Chemical accidents reported in news media in OECD, non-OECD and EU countries, October 2016-September 2017 117
Figure 5.18 Number of chemical accidents in OECD countries with significant releases to the environment 118

## 6/ Concentrations of chemicals in the environment and humans

Figure 6.1 Value chain of the chemical industry, showing emissions and concentrations 121
Figure 6.2 Exposure pathways 122
Figure 6.3 Links between the near-field environment and compartment of entry, the far-field environment, and the human body 123
Figure 6.4 Trends in DDT concentrations in air, and ratios between DDT and total DDTs ($pg/m^3$), in Hedo, Japan, 2009-2013 127
Figure 6.5 Trends in concentrations of PCBs in Košetice, Czech Republic ($pg/m^3$), 1996-2013 127
Figure 6.6 Global atmospheric concentrations of polybrominated diphenyl ethers (PBDEs) and of organophosphate esters (OPEs) and other novel flame retardants (FRs) at four location types: polar, background, rural and urban, 2014 129
Figure 6.7 Number of pharmaceuticals detected in surface water, groundwater, tap water and/or drinking water 132
Figure 6.8 Concentrations of polybrominated diphenyl ethers (PBDEs) in surface soil by land use category (ng/g) 134
Figure 6.9 Mercury concentrations in large lake trout collected from the East Arm of Great Slave Lake, Canada (μg/g), 1992-2012 137

Figure 6.10 Mercury concentrations in polar bears, Svalbard, Norway (ng/g dw), 1960s-2000s 137
Figure 6.11 Blood concentrations (μg/kg plasma lipid) of p,p-DDE in pregnant Inuit women from Nunavik, Canada, 1992-2017 138
Figure 6.12 Concentrations of PFHxS and PFDA (μg/kg) in the blood of Swedish first-time mothers, 1996-2010 139
Figure 6.13 Levels of PCDD/PCDF (Sum 17 PCDD/PCDF) and indicator PCB (Sum 6 PCB) in human milk: survey results in 2005-2010 and comparison with 1980s levels 140
Figure 6.14 Concentrations of perfluorinated compounds in the blood serum of women in the United States, 1999-2014 (median ng/ml) 141
Figure 6.15 Concentrations of mercury and selenium in women's blood, Nunavik (Canada) (μg/L), 1992-2012 142
Figure 6.16 Mercury concentrations in cord blood from birth cohort studies by country (μg/L), 2003-2016 143

## 7/ Environmental, health and social effects of chemicals

Figure 7.1 Deaths (total: 1.6 million) attributed to selected chemicals (per cent), 2016 150
Figure 7.2 Deaths and DALYs from occupational exposure to cadmium, 1990-2017 157
Figure 7.3 Percentage of deaths attributed to unintentional poisonings by selected chemicals by age, 2016 159
Figure 7.4 Deaths attributed to selected chemicals, by gender, 2016 161

## 8/ The economic benefits of action and the costs of inaction

Figure 8.1 Identifying the economic costs of inaction and the benefits of action 167
Figure 8.2 Lost lifetime earning potential for each cohort of children under five from childhood lead exposure in 2011 (US dollars billion) 171

# II. Where do we stand in achieving the 2020 goal – assessing overall progress and gaps

## 2/ Reporting schemes and indicators under international agreements and frameworks

Figure 2.1 Compliance with national reporting obligations, 2016: Basel and Stockholm Conventions 231
Figure 2.2 Historical evolution of general compliance with national reporting obligations: Basel and Stockholm Conventions, 2001-2015 232
Figure 2.3 Average national reporting rate 2001-2016, by category of countries (developed/developing) and by regions: Basel and Stockholm Conventions 232

## 3/ Achieving the 2020 goal: what do we know?

Figure 3.1 Parties to the Basel Convention, as at January 2019 244
Figure 3.2 Basel Convention implementation: Parties which have used the option to adopt a national definition of hazardous waste, as at January 2019 244
Figure 3.3: Parties to the Rotterdam Convention, as at January 2019 245
Figure 3.4 Parties to the Stockholm Convention, as at January 2019 246

Figure 3.5 Countries with National Implementation Plans (NIPs) under the Stockholm Convention , as at January 2019 247
Figure 3.6 Parties to the Minamata Convention, as at January 2019 248
Figure 3.7 Countries which have undertaken Minamata Initial Assessments (MIAs), as at January 2019 249
Figure 3.8 Parties with National Action Plans (NAPs) for artisanal and small-scale gold mining, as at January 2019 249
Figure 3.9 Countries with core capacities for chemicals under the International Health Regulations (2005), 2018 251
Figure 3.10 National profiles to assess the chemicals and management infrastructure, 2018 260
Figure 3.11 Engagement of sectors in coordination mechanisms, comparing results for 2009-2010 and 2011-2013 261
Figure 3.12 Global GHS implementation status, 2018 264
Figure 3.13 Pollutant Release and Transfer Registers, 2018 265
Figure 3.14 Progress in environmental and health monitoring, comparing results for 2009-2010 and 2011-2013 266
Figure 3.15 Countries with pesticide legislation, according to FAO data collected in the context of the Code of Conduct, February 2018 271
Figure 3.16 Countries that have banned the use of asbestos, August 2018 271
Figure 3.17 Global status of phasing out lead in gasoline, March 2017 272
Figure 3.18 Trends the in use of IOMC tools for risk reduction for the reporting period 2011–2013 272
Figure 3.19 Existence and distribution of poisons centres, September 2017 273
Figure 3.20 Trends in private sector financial support comparing results for 2009-2010 and 2011-2013 276
Figure 3.21 Trends in industry participation in multi-stakeholder committees comparing results for 2009-2010 and 2011-2013 276
Figure 3.22 Countries with a chemical industry which have implemented the Responsible Care® programme as of March 2017 277
Figure 3.23 Resource allocations for chemicals and waste by GEF round, 1994-2018 278
Figure 3.24 GEF-6 projects by chemical group 279
Figure 3.25 Overview of the Quick Start Programme since 2006 280
Figure 3.26 Increase in percentage of developing country governments with development assistance programmes that address chemicals comparing results for 2009-2010 and 2011-2013 281
Figure 3.27 Comparison of results of the 2015 ICCA progress report with the 2009 baseline for SAICM indicators under capacity building and technical cooperation 282
Figure 3.28 Selected SAICM indicators, comparing results for 2009-2010 and 2011-2013 287
Figure 3.29 Progress against objectives since the first reporting period, by region for the reporting period 2011–2013 (per cent) 288

## 4/ Emerging policy issues and other issues of concern

Figure 4.1 Economic costs of childhood lead exposure in low- and middle-income countries (percentage of gross domestic product) 294
Figure 4.2 Status of lead paint regulation worldwide, as reported in 2017 295
Figure 4.3 The life cycle of electronic and electrical products 296
Figure 4.4 Percentage of the world population and number of countries covered by e-waste legislation in 2014 and 2017 298
Figure 4.5 Discomfort or illness experienced during or after pesticide application in Mozambique 300
Figure 4.6 Conversion process from chemical products to articles in the supply chain 303
Figure 4.7 Schematic overview of the structure categories of identified PFASs 308

Figure 4.8 Estimated annual releases of PFCAs from PFOA production sites (left) and fluoropolymer production sites (right) in the United States, Western Europe and Japan (purple), as well as in China, Russia, Poland and India (orange) (t/yr), 1951-2015 309
Figure 4.9 Pathways of antibiotics for human and veterinary use in the environment 312
Figure 4.10 Milestones in the development of the EDC field, 1958-2013 316

# III. Advancing and sharing chemicals management tools and approaches: taking stock, looking into the future

## 1/ Hazard assessment: progress in information generation and hazard characterization

Figure 1.1 From risk assessment to risk management 385
Figure 1.2 Graphical representation of a chemical category and some approaches for filling data gaps 389
Figure 1.3 Testing and assessment based on the Adverse Outcome Pathway (AOP) concept 390

## 2/ Exposure assessment: benefiting from internationally available resources

Figure 2.1 Aggregate (left) and cumulative (right) exposure 400
Figure 2.2 Transfer fractions to near-field and far-field compartments and the corresponding product intake fraction for phenoxyethanol used as a preservative at a concentration of 0.86 per cent in a hand lotion 404

## 4/ Risk management decision-making: making it work in all countries

Figure 4.1 Hazard pictograms according to the GHS 422
Figure 4.2 Risk assessment and socio-economic assessment (SEA) 432

## 6/ Chemical risk management in facilities and during production

Figure 6.1 Stakeholders in the change of ownership of hazardous facilities 457

## 7/ Approaches to sustainability assessment

Figure 7.1 Conceptual relationships of the main chemical management tools 469
Figure 7.2 General structure of the life cycle assessment (LCA) framework 470
Figure 7.3 Elements of a comprehensive framework to evaluate global chemical supply chain impacts on humans and the environment 473

# IV. Enabling policies and action to support innovative solutions

## 1/ Envisioning and shaping the future of chemistry


Figure 1.1 Examples of how chemistry contributes to industries expected to play important roles in the future 506
Figure 1.2 Dimensions of a chemical enterprise: towards sustainability 509
Figure 1.3 Market size of the global green chemistry industry, 2015-2020 (US dollars billion) 510
Figure 1.4 Global green chemicals market by region (US dollars billion), 2011-2020 511
Figure 1.5 The four industrial revolutions 512
Figure 1.6 Overview of the implications of digitalization in the chemical industry 513


## 2/ Green and sustainable chemistry education: nurturing a new generation of chemists


Figure 2.1 Number of papers published on GSCE, 1998-July 2018, concerning green chemistry education or sustainable chemistry education 518
Figure 2.2 Number of papers published on GSCE, 1998-July 2018 518
Figure 2.3 Steps to promote GSCE 520


## 3/ Strengthening sustainable chemistry technology innovation and financing


Figure 3.1 Innovation ecosystem model 525
Figure 3.2 Technology innovation chain and key enabling factors 526
Figure 3.3 Stage of technology readiness and the Valley of Death 527
Figure 3.4 Venn diagram of incubator and accelerator characteristics 534
Figure 3.5 Venturing tools supporting start-ups at different innovation phases 534
Figure 3.6 Start-up development stages and typical investors along the innovation chain (Swedish krona thousand) 536
Figure 3.7 Chemical industry leaders´ view of the evolution of the intensity of collaboration with other stakeholders 537
Figure 3.8 New collaboration approaches in the chemical industry 539
Figure 3.9 Policy interventions that foster technology innovation 540


## 4/ Evolving and new business models


Figure 4.1 Traditional business models vs. Chemical Leasing 544
Figure 4.2 Visible and hidden chemicals management costs 545
Figure 4.3 Global growth of eco-industrial parks (EIPs) 546
Figure 4.4 Eco-industrial parks' sources of revenue 547
Figure 4.5 Evolution of a social enterprise 552


## 5/ Fiscal incentives to advance sound chemicals management and sustainable chemistry


Figure 5.1 Marginal cost of reducing the use of trichloroethylene (TCE) in metal degreasing 557
Figure 5.2 Effects of differentiated taxation on quantities of pesticides sold in Norway, 1997-2008 559

## 6/ Sustainable supply chain management for chemicals and waste in the life cycle

Figure 6.1 Interface of demand and supply in driving the sustainability of chemicals in the supply chain 565
Figure 6.2 Sustainable Supplier Relationship Management (SSRM) practices 570

## 7/ Sustainability metrics and reporting: measuring progress, strengthening accountability

Figure 7.1 Share of the top 100 companies in 34 countries (N100) and of the world's 250 largest companies providing corporate responsibility reports (per cent), 1993-2017 576
Figure 7.2 Snapshot of Sumitomo's Corporate Social Responsibility Report: work-related incident rate (per cent), 2011-2015 577
Figure 7.3 ZDHC and PUMA's rates of compliance with MRSL parameters in wastewater (per cent), 2017 578
Figure 7.4 Average percentage of points across four Chemical Footprint Project (CFP) pillars scored by small, medium and large companies selling only articles 580

## 8/ Empowering and protecting citizens, workers and consumers

Figure 8.1 DOZN scoring example 595
Figure 8.2 Citizen science project to monitor the concentration of neonicotinoids in honey, November 2012 and February 2016 597
Figure 8.3 Human rights impacts by life cycle stage, information received between 2012-2017 601

# V. Scaling up collaborative action under the 2030 Agenda for Sustainable Development

## 1/ The 2030 Agenda for Sustainable Development: an integrated framework for action

Figure 1.1 The three dimensions of sustainability 630
Figure 1.2 Linkages between chemicals and waste and the SDGs 631
Figure 1.3 Alignment of the Dow 2025 Sustainability Goals with the SDGs 634
Figure 1.4 Building blocks for a collaborative society 638
Figure 1.5 A multisectoral collaboration model to achieve transformative change 639

# List of Tables

## Introduction: chemicals and waste in the broader sustainable development context


### 1/ The global context for the sound management of chemicals and waste

Table 1.1 Chemicals and waste in the 2030 Agenda for Sustainable Development: SDG Targets 3.9 and 12.4 — 2


## I. The evolving chemicals economy: status and trends relevant for sustainability


### 2/ Trends in production and sales of specific chemicals

Table 2.1 Total global chemical shipments, 2016 and 2017 (US dollars billion) — 42
Table 2.2 Overview of estimated total production of PCBs — 43
Table 2.3 Global production capacity for petrochemicals, 2016 — 44
Table 2.4 Evolution of global production capacity for primary petrochemical building blocks (kg per capita) — 45
Table 2.5 Global manufacture of pesticide active ingredients by region, 2008-2016 (thousand kg) — 46
Table 2.6 Top 10 products used on major crops in the United States by volume, 1968 and 2016 — 47
Table 2.7 Geographic distribution of fluoropolymer consumption in 2015 in tonnes (per cent share) — 50
Table 2.8 Global refined lead production and usage (thousand tonnes), 2013-2018 — 52
Table 2.9 Global mercury supply, 2015 (tonnes) — 54
Table 2.10 Cadmium: refinery production by country, 2012-2016 (tonnes) — 55
Table 2.11 World production of rare earth mineral concentrates (thousand tonnes) and total estimated increase (per cent), 1990-2015 — 56

### 3/ Megatrends and chemical-intensive industry sectors: risks and opportunities

Table 3.1 Matrix analysis of megatrend studies — 62
Table 3.2 World population prospects (millions) — 63
Table 3.3 Major end markets for four primary commodity chemical groups — 69
Table 3.4 End markets for chemicals — 69

### 4/ Global supply chains, chemicals in products, and circularity

Table 4.1 Actors, main impact drivers and exposure over the product life cycle of toys — 81
Table 4.2 Examples of studies identifying unintended chemical contaminants in products — 85

## 5/ Chemical pollution: emissions, releases and wastes

Table 5.1 Hazardous and non-hazardous wastes from six African countries (tonnes/year), 2012 110
Table 5.2 Hazardous waste generation in selected countries, 2014 (tonnes) 114
Table 5.3 Resource efficiency in the chemical industry: ratio of products and waste generation 115

## 7/ Environmental, health and social effects of chemicals

Table 7.1 Total number of agents and POPs classified by the IARC Monographs per group (Volumes 1-123) 152
Table 7.2 Chemicals identified by Grandjean and Ladrigan (2014) as being toxic to the human nervous system, 2006 and 2013 155

# II. Where do we stand in achieving the 2020 goal – assessing overall progress and gaps

## 1/ International agreements and frameworks on chemicals and waste

Table 1.1 Multilateral agreements related to the sound management of chemicals and waste 221

## 2/ Reporting schemes and indicators under international agreements and frameworks

Table 2.1 IOMC Indicators and linkages to other policy instruments 238
Table 2.2 SDGs 3, 6, 11 and 12 with targets, indicators, custodian and partner agencies, and linkages to OOG elements 240

## 3/ Achieving the 2020 goal: what do we know?

Table 3.1 Estimates of progress made towards elimination of PCBs use per UN region, 1990-2015 248
Table 3.2 Examples of regional institutions and initiatives addressing chemicals and waste in the African region 252
Table 3.3 Examples of regional institutions and initiatives addressing chemicals and waste in the Asia and the Pacific region 254
Table 3.4 Examples of regional institutions and initiatives addressing chemicals and waste in Europe 255
Table 3.5 Examples of regional institutions and initiatives addressing chemicals and waste in Latin America and the Caribbean 256
Table 3.6 Examples of regional institutions and initiatives addressing chemicals and waste in North America 258
Table 3.7 Examples of regional institutions and initiatives addressing chemicals and waste in the West Asia region 259
Table 3.8 Examples of science policy bodies and mechanisms 267
Table 3.9 Stakeholder perceptions of the degree of success regarding prevention of illegal international traffic in chemicals and waste from 2006-2015, asked between 14 November 2016 to 4 January 2017 285
Table 3.10 Stakeholder perceptions of the degree of success in achieving OPS objectives from 2006-2015, asked between 14 November 2016 to 4 January 2017 289

Table 3.11 Stakeholder perceptions of the degree of success in incorporating the SAICM emerging policy issues (EPIs) and other issues of concern in activities from 2006-2015, asked between 14 November 2016 to 4 January 2017 290

## III. Advancing and sharing chemicals management tools and approaches: taking stock, looking into the future

### 1/ Hazard assessment: progress in information generation and hazard characterization

Table 1.1 Health hazards and environmental hazards – classes for global hazard classification 391

### 4/ Risk management decision-making: making it work in all countries

Table 4.1 Forms of standards complemented with international examples relevant to chemicals and waste management 426

### 5/ Assessment of chemical and non-chemical alternatives: focusing on solutions

Table 5.1 A functional substitution approach for chemicals in products and processes 437
Table 5.2 Components of an alternatives assessment 438
Table 5.3 Examples in the literature referring to potential regrettable substitution 443
Table 5.4 Examples of treaties, regulatory actions and non-regulatory initiatives with provisions for alternatives assessment or substitution 446

### 6/ Chemical risk management in facilities and during production

Table 6.1 Selected activities of organizations engaged in addressing chemical accidents 454

## IV. Enabling policies and action to support innovative solutions

### 2/ Green and sustainable chemistry education: nurturing a new generation of chemists

Table 2.1 Sustainable chemistry teaching: laboratory content 516

### 3/ Strengthening sustainable chemistry technology innovation and financing

Table 3.1 Institutional venturing tools 533
Table 3.2 Potential private investors for sustainable chemistry start-ups 535
Table 3.3 Examples of investments in sustainable chemistry start-ups by different investors 535
Table 3.4 The corporate approach to start-up development 538
Table 3.5 Examples of push and pull policies to advance sustainable chemistry innovation 540

## 5/ Fiscal incentives to advance sound chemicals management and sustainable chemistry

Table 5.1 Types of market-based instruments and examples of their application to chemicals management 556

## 6/ Sustainable supply chain management for chemicals and waste in the life cycle

Table 6.1 From traditional to green and biomimetic chemistry technologies 574

# V. Scaling up collaborative action under the 2030 Agenda for Sustainable Development

## 1/ The 2030 Agenda for Sustainable Development: an integrated framework for action

Table 1.1 Indicative mapping of IOMC participating organizations' activities on the SDGs for sound chemicals and waste management 636

## 2/ Strengthening collaborative action on chemicals and waste in line with the 2030 Agenda

Table 2.1 Integrating chemicals and waste management, and green and sustainable chemistry innovation, in relevant economic sectors: some opportunities 644
Table 2.2 Examples of opportunities for the contribution of international chemicals and waste agreements across economic sectors 645
Table 2.3 Example of a results chain to minimize adverse impacts 650

# List of Boxes

## I. The evolving chemicals economy: status and trends relevant for sustainability


### 1/ The chemical industry

Box 1.1 Women in leadership positions in the chemical industry 36
Box 1.2 The benefits of thorough due diligence during mergers and acquisitions 39

### 2/ Trends in production and sales of specific chemicals

Box 2.1 Microplastics 60

### 3/ Megatrends and chemical-intensive industry sectors: risks and opportunities

Box 3.1 Lead-acid batteries: avoiding future legacies 75

### 4/ Global supply chains, chemicals in products, and circularity

Box 4.1 An example of challenges related to the interface of chemicals, waste and circularity: the phthalate plasticizer DEHP in PVC 88

### 5/ Chemical pollution: emissions, releases and wastes

Box 5.1 Outcomes of the effectiveness evaluation of the Stockholm Convention 96
Box 5.2 Releases of chemicals used in fracking 101

### 6/ Concentrations of chemicals in the environment and humans

Box 6.1 Bioaccumulation and biomagnification 122
Box 6.2 Concentrations of legacy chemicals in water bodies: the Mariana and Kermadec trenches and Lake Geneva 131

### 7/ Environmental, health and social effects of chemicals

Box 7.1 Coral reefs are under threat from chemical pollution 148
Box 7.2 Endocrine-disrupting chemicals 153

### 8/ The economic benefits of action and the costs of inaction

Box 8.1 Externalities: the differences between market prices and social costs 165
Box 8.2 Current methodological developments: SACAME 168
Box 8.3 Utility, economic value and economic cost 169

# II. Where do we stand in achieving the 2020 goal – assessing overall progress and gaps

## 1/ International agreements and frameworks on chemicals and waste

Box 1.1 The elements of the Strategic Approach to International Chemicals Management 225

## 2/ Reporting schemes and indicators under international agreements and frameworks

Box 2.1 The reporting mechanism for the WHO IHR 233
Box 2.2 SAICM indicators of progress 236
Box 2.3 The SAICM Overall Orientation and Guidance (OOG) 237

## 3/ Achieving the 2020 goal: what do we know?

Box 3.1 Synergies across multilateral treaties on chemicals and waste 250
Box 3.2 SAICM Implementation Plan for Guyana 261
Box 3.3 Potential considerations for the selection of future issues of global concern 268
Box 3.4 Identified challenges in creating a coherent global knowledge base: lessons for strengthening the science-policy interface 268
Box 3.5 SAICM independent evaluation: on-line survey of stakeholders 289

## 4/ Emerging policy issues and other issues of concern

Box 4.1 Preventing suicides attributable to pesticides through regulatory measures in Sri Lanka 301
Box 4.2 The Higg Index: advancing sustainability in the apparel industry 304
Box 4.3 Helping doctors to make informed prescription choices 313
Box 4.4 First standardized test method specifically for nanomaterials adopted by the OECD 315

# III. Advancing and sharing chemicals management tools and approaches: taking stock, looking into the future

## 1/ Hazard assessment: progress in information generation and hazard characterization

Box 1.1 The eChemPortal 393
Box 1.2 The European Chemicals Agency's longer-term vision for improving access to information 394

## 2/ Exposure assessment: benefiting from internationally available resources

Box 2.1 Human exposure to chemicals – environmental pathways 397
Box 2.2 Programmes to monitor chemicals in humans and the environment 398
Box 2.3 OECD Emission Scenario Documents (ESDs) 402

## 3/ Risk assessment: opportunities to improve and accelerate progress


| | | |
|---|---|---|
| Box 3.1 | Canada's Chemicals Management Plan | 408 |
| Box 3.2 | The WHO Human Health Risk Assessment Toolkit | 410 |
| Box 3.3 | The OECD Environmental Risk Assessment Toolkit | 410 |
| Box 3.4 | Assessing exposure to chemical mixtures: WHO and EFSA activities | 412 |
| Box 3.5 | The WHO One Health initiative | 413 |
| Box 3.6 | Solution-focused risk assessment | 415 |


## 4/ Risk management decision-making: making it work in all countries


| | | |
|---|---|---|
| Box 4.1 | Tools used by retailers to identify hazardous chemicals in their products and to select safer and greener alternatives | 431 |
| Box 4.2 | Decision-making for industrial chemicals: the IOMC Toolbox | 434 |


## 5/ Assessment of chemical and non-chemical alternatives: focusing on solutions


| | | |
|---|---|---|
| Box 5.1 | Dental amalgam – informed substitution in developing countries | 440 |
| Box 5.2 | Proactive substitution by frontrunners: safer alternatives for brominated flame retardants in the electronics sector | 442 |
| Box 5.3 | Replacing highly hazardous pesticides through Integrated Pest Management and non-chemical alternatives | 444 |
| Box 5.4 | The mix of regulatory and non-regulatory policies to support informed substitution | 447 |
| Box 5.5 | The importance of policies that include technical support structures: chlorinated solvent substitution | 448 |
| Box 5.6 | Substitution of methyl bromide: the importance of having a range of alternatives and stakeholder engagement | 450 |
| Box 5.7 | Mercury-free hospitals: the importance of participatory substitution programmes and alternative technology replacements | 451 |


## 6/ Chemical risk management in facilities and during production


| | | |
|---|---|---|
| Box 6.1 | Lessons learned from Natech accidents triggered by Hurricane Harvey | 459 |
| Box 6.2 | Formalizing artisanal and small-scale gold mining | 466 |


# IV. Enabling policies and action to support innovative solutions

## 1/ Envisioning and shaping the future of chemistry


| | | |
|---|---|---|
| Box 1.1 | The 12 Principles of Green Chemistry | 508 |


## 2/ Green and sustainable chemistry education: nurturing a new generation of chemists


| | | |
|---|---|---|
| Box 2.1 | Examples of universities offering courses in green and sustainable chemistry | 517 |
| Box 2.2 | Green chemistry and sustainability in professional education and training courses: a case study from Brazil | 519 |

Box 2.3 The CHEM21 online learning platform 522

## 3/ Strengthening sustainable chemistry technology innovation and financing

Box 3.1 Recommended actions for universities in low- and middle-income countries facing the challenge of transforming themselves into third generation universities 528
Box 3.2 Insights from entrepreneurs on challenges for sustainable chemistry start-ups 531
Box 3.3 Selected sustainable chemistry awards and pitching events targeting start-up 532
Box 3.4 Open collaborations in sustainable chemistry innovation 539

## 4/ Evolving and new business models

Box 4.1 Chemical Leasing in a middle-income country: wastewater treatment in Colombia 544
Box 4.2 The Shanghai Chemical Industry Park 548
Box 4.3 Ocean Sole: a social enterprise in Kenya 552

## 5/ Fiscal incentives to advance sound chemicals management and sustainable chemistry

Box 5.1 Shifting taxes from labour to resource use and pollution 556
Box 5.2 Risk-based pesticide taxation in Norway and Denmark 558
Box 5.3 The fertilizer subsidy programme in India 559
Box 5.4 Chemical taxes on consumer products in Denmark and Sweden 560
Box 5.5 Different effects of charges on plastic bags in Ireland and South Africa 560
Box 5.6 The waste electric and electronic equipment (WEEE) recycling fund in China 562

## 6/ Sustainable supply chain management for chemicals and waste in the life cycle

Box 6.1 Examples of chemical sustainability initiatives in the retail sector 566
Box 6.2 Downstream sector sustainable supply chain initiatives addressing chemicals of concern 567
Box 6.3 Together for Sustainability: chemical industry collaboration with suppliers to advance sustainability 568
Box 6.4 Strengthening information flows between the chemical industry to downstream customers 569
Box 6.5 The Circular Economy Package 572
Box 6.6 The Design Thinking approach to advance sustainability 573

## 7/ Sustainability metrics and reporting: measuring progress, strengthening accountability

Box 7.1 Johnson’s Greenlist™ Programme 579
Box 7.2 Sustainability information of relevance to the financial sector 581

## 8/ Empowering and protecting citizens, workers and consumers

Box 8.1 Excerpts from paragraph 15 of the SAICM Overarching Policy Strategy (OPS) 591
Box 8.2 The US EPA’s Chemical Access Data Tool 592
Box 8.3 Examples of mobile applications for disseminating chemical information 594
Box 8.4 Cases of human rights protection in matters of chemicals and waste 600

# V. Scaling up collaborative action under the 2030 Agenda for Sustainable Development

## 1/ The 2030 Agenda for Sustainable Development: an integrated framework for action

Box 1.1 Planetary boundaries, chemicals and waste, and the 2030 Agenda: a research perspective 635

## 2/ Strengthening collaborative action on chemicals and waste in line with the 2030 Agenda

Box 2.1 The WHO Chemicals Road Map 643
Box 2.2 The integrated results and indicator framework under the Strategic Plan for Biodiversity 648

# Introduction: chemicals and waste in the broader sustainable development context

## Contents

1/ The global context for the sound management of chemicals and waste 2

2/ Milestones in international chemicals and waste management 5

3/ Opportunities to link international policy agendas 10

4/ Overview of the Global Chemicals Outlook II 14

References 15

# 1/ The global context for the sound management of chemicals and waste

The *Global Chemicals Outlook II* (GCO-II) is released at a crucial moment. Since the publication of the GCO-I in 2013, the global consumption and production of chemicals[1] has continued to grow, with a number of trends that are a cause for concern about human health and the environment. This period also witnessed the adoption in 2015 of the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), which include several targets specifically related to chemicals and waste management. Shortly thereafter, the International Conference on Chemicals Management (ICCM), which is the governing body of the Strategic Approach to International Chemicals Management (SAICM), initiated an intersessional process to prepare by 2020 recommendations regarding the Strategic Approach and the sound management of chemicals and waste beyond 2020. By using a back-casting approach that envisaged a sustainable future, the GCO-II has identified a range of actions for consideration by policymakers around the world and informing chemicals and waste management beyond 2020.

## Production, use and trade of chemicals are growing in all regions, driven by global megatrends

Global income levels are rising and the global middle class is expanding, creating increasing demand for a range of goods and products for which chemistry is essential. Chemical-intensive industry sectors (e.g. construction, agriculture, electronics, cosmetics, mining and textiles) are growing, affecting market demand for chemicals and creating both risks and opportunities. In light of these trends and the changing consumption and production patterns that accompany them, the chemical industry is growing rapidly. The production and consumption of chemicals has spread worldwide, with an increasing share now located in low- and middle-income countries, many of which may have limited regulatory capacity. Cross-border trade in chemicals and products is also growing, and increasing amounts of chemicals are shipped through long and complex global supply chains.

**Table 1.1** Chemicals and waste in the 2030 Agenda for Sustainable Development: SDG Targets 3.9 and 12.4

| | |
|---|---|
| **SDG 3: Ensure healthy lives and promote well-being for all at all ages** | |
| 3 GOOD HEALTH AND WELL-BEING | **Target 3.9**: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination. |
| **SDG 12: Ensure sustainable consumption and production patterns** | |
| 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | **Target 12.4**: By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment. |

1 The term "chemicals" is understood throughout this report to include pharmaceuticals, unless otherwise noted.

## Sound management and innovations in chemistry are essential for sustainable development

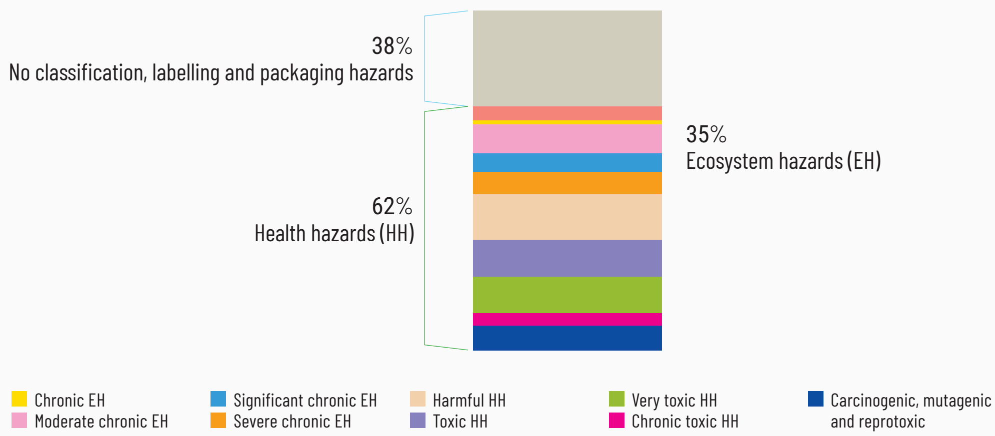
From pharmaceuticals and plant protection products to the production of cars, computers and textiles, many manufactured chemicals have helped improve human health, food security, productivity and quality of life throughout the world. While the number of chemicals registered by the American Chemical Society's global Chemical Abstracts Service exceeds 142 million, only a fraction of these chemicals are placed on the market (American Chemistry Council [ACC] 2018).

A 2019 report jointly developed by the United Nations Environment Programme and the International Council of Chemical Associations estimated the total number of industrial chemicals in commerce globally at 40,000 to 60,000, with 6,000 of these chemicals accounting for more than 99 per cent of the total volume (United Nations Environment Programme [UNEP] and International Council of Chemical Associations [ICCA] 2019). The number of chemicals on the market is exceeded by a larger – and growing – number of chemical-intensive products such as computers, mobile phones, furniture and personal care products – with billions of items sold each year.

Many chemicals, products and wastes have hazardous properties and continue to cause significant adverse impacts on human health and the environment because they are not properly managed. Chemicals or groups of chemicals that are receiving attention in research and policymaking because of their hazardous properties and potential risks include, but are not limited to, carcinogens, mutagens and chemicals hazardous to reproduction, persistent bio-accumulative and toxic substances, endocrine-disrupting chemicals, and chemicals with neurodevelopmental effects. According to 2018 data compiled by the European Environment Agency (EEA), approximately 62 per cent of the total volume of chemicals consumed in the European Union (EU) in 2016 were hazardous to health (EEA 2018).

Ensuring the sound management of chemicals and waste, as called for internationally at the highest political level during several major United Nations Conferences, is essential to advance sustainable development across its

**Figure 1.1** Share of the volume of chemicals consumed in the European Union in 2016 by hazard categories (based on European Environment Agency 2018)




According to data from Eurostat (the statistical office of the EU) compiled in 2018 by the European Environment Agency, approximately 62 per cent of the 345 million tonnes of chemicals consumed in the EU in 2016 were hazardous to health. In presenting the data, the Agency noted that volumes of hazardous chemicals consumed are not a proxy for the risks posed by those chemicals.

social, economic and environmental dimensions. Chemistry and the chemical industry have important roles to play in achieving the sound management of chemicals and waste within a sustainable development context. Addressing legacies, coupled with innovations in chemistry and materials science, has the potential to create safer chemicals, increase resource efficiency, and reduce the health and environmental impacts associated with the current global production and consumption system.

# 2/ Milestones in international chemicals and waste management

The transboundary movement of chemicals through the air or water, as well as international trade in chemicals and products, call for global collaborative action to minimize adverse impacts. For several decades the international community has recognized the need for action. It has undertaken various initiatives to advance the sound management of chemicals and waste, which have played an important role in global efforts to minimize their adverse impacts. In developing a future framework for the sound management of chemicals and waste beyond 2020, valuable lessons can be learned from their design and implementation. Some of these initiatives are explored in more detail in Part II of the GCO-II, where progress towards the sound management of chemicals and waste is assessed.

## From early action to the Rio Earth Summit

Examples of early action include the International Labour Organization (ILO) White Lead (Painting) Convention (1921), the establishment of the Codex Alimentarius Commission (1961), and the United Nations Recommendations on the Transport of Dangerous Goods (1956). At the 1992 United Nations Conference on Environment and Development (UNCED), also known as the Rio Earth Summit, Heads of State and Government adopted Agenda 21, an international action plan which promoted an integrated life cycle approach and contained dedicated chapters on the environmentally sound management of toxic chemicals (Chapter 19) and hazardous wastes (Chapter 20). Also adopted in 1992, the Rio Declaration on Environment and Development contained a number of principles and approaches relevant to the sound management of chemicals and waste, including the polluter pays principle, the right-to-know, and the precautionary approach.

## The 2002 Johannesburg Plan of Implementation and the 2020 timeline

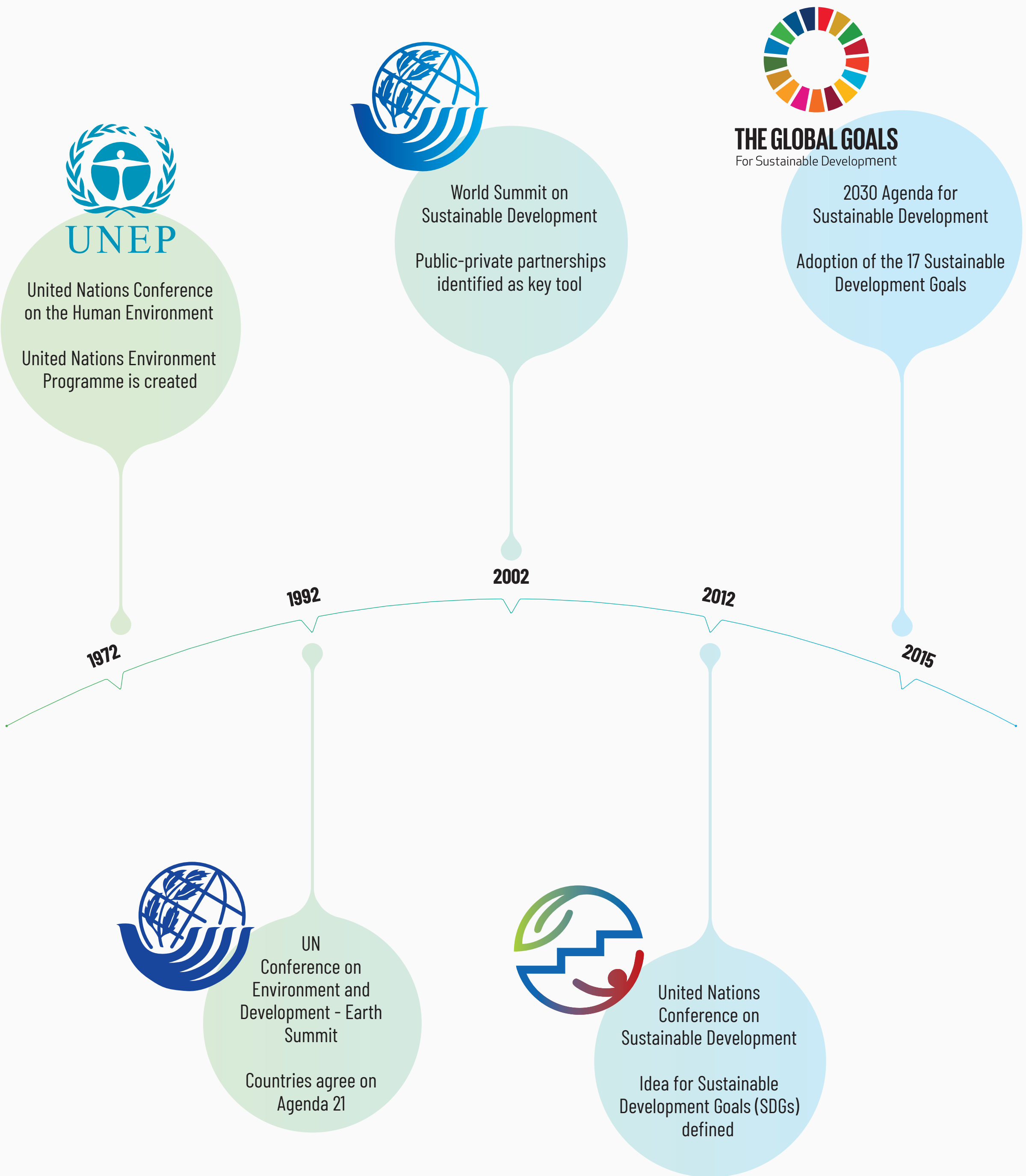
In 2002 the World Summit on Sustainable Development (WSSD) adopted the Johannesburg Plan of Implementation (JPOI), in which Governments agreed to "renew the commitment, as advanced in Agenda 21, to sound management of chemicals throughout their life cycle and of hazardous wastes for sustainable development as well as for the protection of human health and the environment, inter alia, aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment [...]" (paragraph 23) (UN 2002). Countries further agreed to "using transparent science-based risk assessment procedures and science-based risk management procedures, taking into account the precautionary approach [...], and support developing countries in strengthening their capacity for sound management of chemicals and hazardous wastes by providing technical and financial assistance". A number of actions at all levels to achieve these goals were outlined, including to:

- promote the ratification and implementation of relevant international instruments;
- develop a strategic approach to international chemicals management;
- implement the globally harmonized system for the classification and labelling of chemicals;
- encourage partnerships;
- promote efforts to prevent international illegal trafficking;

- encourage development of coherent and integrated information on chemicals, e.g. through Pollutant Release and Transfer Registers (PRTRs); and
- promote reduction of the risks posed by heavy metals (UN 2002).

The 2020 timeline was reiterated at the Rio plus 20 Summit in 2012 (referring to chemicals and hazardous waste) (UN 2012), as well as in the 2030 Sustainable Development Agenda through SDG Target 12.4 (referring to chemicals and all wastes). SDG Target 3.9, which focuses on reducing deaths and illnesses, features a 2030 timeline.

**Figure 2.1** Key milestones in global sustainable development governance (which also included the sound management of chemicals and waste)



### Multilateral treaties and voluntary agreements

Since around the time of the Rio Summit and in the following decades, the international community has taken concerted action through multilateral treaties on specific hazardous chemicals and issues of global concern. Prominent examples, explored in greater detail in Part II, include the following:

- Montreal Protocol on Substances that Deplete the Ozone Layer (entry into force in 1989)
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (entry into force in 1992)
- International Labour Organization (ILO) Conventions C170 - Chemicals Convention (entry into force in 1993) and C174 - Prevention of Major Industrial Accidents Convention (entry into force in 1997)
- Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (entry into force in 2004)
- Stockholm Convention on Persistent Organic Pollutants (POPs) (entry into force in 2004)
- World Health Organization (WHO) International Health Regulations (IHR) (2005) (entry into force in 2007)
- Minamata Convention on Mercury (entry into force in 2017)

Moreover, several voluntary international instruments adopted by the governing bodies of international organizations address a range of chemicals and issues. Prominent examples include the International Code of Conduct on Pesticide Management (hereinafter referred to as the "Code of Conduct"), originally developed in 1985 with a fourth version adopted in 2013, and the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), which was adopted in 1992. The GHS was specifically mentioned in the 2002 Johannesburg Plan of Implementation with a view to the system being fully operational by 2008.

### Adoption of the Strategic Approach to International Chemicals Management in 2006

In 2006, following the call made at the WSSD, the Strategic Approach to International Chemicals Management (SAICM) was adopted by the first session of the ICCM (ICCM1) as a multi- and cross-sectoral and participatory strategic approach. SAICM's overall objective is "to achieve the sound management of chemicals throughout their life cycle so that by the year 2020, chemicals are produced and used in ways that minimize significant adverse impacts on the environment and human health" (Secretariat of the Strategic Approach to International Chemicals Management [SAICM Secretariat], UNEP and WHO 2006). SAICM comprises the Dubai Declaration on International Chemicals Management, which expressed high-level political commitment to SAICM, and an Overarching Policy Strategy (OPS).

BASEL CONVENTION ROTTERDAM CONVENTION STOCKHOLM CONVENTION

UN environment United Nations Environment Programme — Ozone Secretariat

International Labour Organization

WHO

MINAMATA CONVENTION ON MERCURY

The Overarching Policy Strategy referenced the WSSD 2020 timeline, referring to the "2020 goal", a term subsequently used in various international fora. Objectives to achieve this goal are grouped under five areas: risk reduction, knowledge and information, governance, capacity building and technical cooperation, and illegal international traffic. Furthermore, the Dubai Declaration recommends the use and further development of the Global Plan of Action as a working tool and guidance document for meeting the commitments to chemicals management expressed in, among others, the Johannesburg Plan of Implementation. In 2015, ICCM4 endorsed the "overall orientation and guidance for achieving the 2020 goal of sound management of chemicals" as a voluntary tool that will assist in the prioritization of efforts for the sound management of chemicals and waste as a contribution to the overall implementation of the Strategic Approach.

## Chemicals and waste in the 2030 Sustainable Development Agenda

The 2030 Agenda for Sustainable Development, including its 17 SDGs (Figure 2.2) and 169 targets, was adopted by the United Nations General Assembly at a summit of Heads of State in 2015. The SDGs, which are integrated and indivisible, integrate the three dimensions of sustainable development: economic, social and environmental. While SDG Targets 12.4 and 3.9 are of direct relevance for a range of chemicals and waste management issues, SDG Target 6.3 focuses specifically on improving water quality. The sound management of chemicals and waste is also relevant for the achievement of many other SDGs. Those include halting biodiversity loss, clean water and sanitation, facilitating access to clean energy, climate action, ensuring quality education, and gender equality. Furthermore, implementation of other SDGs is essential in achieving the sound management of chemicals and waste, such as those concerned with education, financing and partnerships.

## Chemicals and sustainability: concerns and opportunities

Despite global agreement reached at high-level UN Conferences and significant action already taken, scientists continue to express concerns regarding the lack of progress towards the sound management of chemicals and waste. These include calls for systemic and transformational changes towards safer chemicals and innovations in chemistry that will contribute to sustainable development.

In this context, "green chemistry" (Anastas and Eghbali 2010), "sustainable chemistry" (Blum

**Figure 2.2** **The Sustainable Development Goals**


Sound management of chemicals and waste cuts across the Sustainable Development Goals. It is relevant for the achievement of much of the 2030 Agenda for Sustainable Development.

*et al.* 2017), "one-world chemistry" (Matlin *et al.* 2016) and related concepts are challenging chemistry to help meet sustainable development needs. Other stakeholders have raised similar concerns. A number of initiatives in the private sector have also identified opportunities to advance sustainability in relation to chemicals. These initiatives include the World Business Council for Sustainable Development (WBCSD) Chemical Sector SDG Roadmap (WBCSD 2017), the Together for Sustainability initiative bringing together 22 companies in the chemical industry, and the Zero Discharge of Hazardous Chemicals (ZDHC) initiative bringing together frontrunner textile companies (ZDHC 2018).

### Intersessional process on the Strategic Approach and the sound management of chemicals and waste beyond 2020

In 2015 Governments and other stakeholders participating in ICCM4 noted that "in most countries more progress has to be made towards actually minimizing the significant adverse effects on human health and the environment that may be associated with some chemical production, use and end-of-life disposal". They also noted "with urgency the limited time remaining to achieve the 2020 goal" (SAICM Secretariat 2015). Shortly after the adoption of the 2030 Agenda in 2015, Governments and other stakeholders participating in ICCM4 initiated a process to prepare recommendations regarding the Strategic Approach and the sound management of chemicals and waste beyond 2020. The Conference agreed that the process should be open to all stakeholders and be concluded by ICCM5 in 2020. The period until ICCM5 in 2020 thus represents a historic window of opportunity for reflection on lessons learned in international chemicals and waste management, some of which has already started within the environment sector, as shown in Resolution 1/5 adopted by the United Nations Environment Assembly (UNEA) in 2014 (United Nations Environment Assembly of the United Nations Environment Programme [UNEA] 2014).


© International Institute for Sustainable Development (IISD), Delegates in plenary at ICCM4 in 2015 in Geneva

# 3/ Opportunities to link international policy agendas

Given the relevance of chemicals and waste across the 2030 Agenda, the beyond 2020 intersessional process provides an opportunity to link and create synergies between chemicals and waste management and other international policy agendas.

## Chemicals and health


The sound management of chemicals and waste plays an important role in avoiding and minimizing risks posed by harmful chemicals in order to protect human health, in particular that of vulnerable populations such as pregnant women, infants and children. While the links between chemicals and health are well-established and the health sector has been an important partner in efforts to minimize risks, further efforts to strengthen linkages between the achievement of SDG Targets 12.4 and 3.9, increase awareness of the important role of the health sector in the management of chemicals, and enhance its participation in international chemicals management activities can build on the UNEA-3 Resolution on chemicals and health (UNEA 2018a), which underlined the importance of chemicals management for human and environmental health, and the WHO Chemicals Road Map, developed based on the World Health Assembly Resolution 69.4 and approved by the 70th World Health Assembly in 2017, which aims to enhance health sector engagement in international chemicals management (WHO 2017).

## Chemicals and the world of work

Workers are among those most exposed to hazardous chemicals in various sectors and across global supply chains. Ratification and implementation of international labour standards help achieve decent work that is safe and healthy, while simultaneously advancing towards greener work processes.

## Chemicals and climate change

Linkages range from the remobilization of chemicals due to melting glaciers, to reducing the greenhouse gas emissions of the chemical industry, to the potential of chemistry to develop adaptation and mitigation solutions. The chemical industry and downstream sectors therefore have an important role to play in achieving the objectives of the Paris Agreement.

## Chemicals and biodiversity

Hazardous chemicals not only affect human health, but also have significant adverse effects on terrestrial and aquatic life. Successful efforts to minimize the risks posed by hazardous chemicals can thus reduce direct pressures on biodiversity. The critical role of pollution and chemicals was recognized in the Strategic Plan for Biodiversity 2011-2020 (UNEP 2010), adopted under the Convention on Biological Diversity. Given current activities to develop a biodiversity framework beyond 2020, opportunities exist to create linkages with the chemicals and waste process beyond 2020.

© Alan D. Wilson, Sow and cub Polar Bears (Ursus maritimus) in the Arctic National Wildlife Refuge, Alaska, CC-BY 3.0

### Chemicals, agriculture and food

Chemicals play a major role with respect to agriculture and food, for example in plant protection and food conservation. This link has long been recognized, and many countries have long-standing legislation to control chemicals used in agriculture and food production. International agreements and bodies that address these and related topics include the Code of Conduct and the Codex Alimentarius, which is a collection of international food standards.

### Chemicals and sustainable consumption and production

Target 12.4 is embedded in SDG 12, “Ensure sustainable consumption and production patterns”, reflecting the insight that chemicals and waste management is inextricably linked to the broader quest for resource efficiency, waste reduction, and the need to decouple economic growth from natural resource use and environmental impacts. Individuals, companies and organizations play a critical role through their consumption choices and

directly or indirectly impact chemicals production and sustainability. The realization that a global shift towards sustainable consumption and production would require the commitment of diverse actors throughout the world spurred Heads of State and Government at Rio+20 to adopt the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns (10YFP) (UNEP 2013). The 10YFP seeks to develop, replicate and scale up sustainable consumption and production policies and initiatives in areas such as public procurement, consumer information, education, construction, and food systems. All of these areas are highly relevant from a chemicals and waste perspective, pointing towards opportunities to strengthen linkages with the 10YFP.

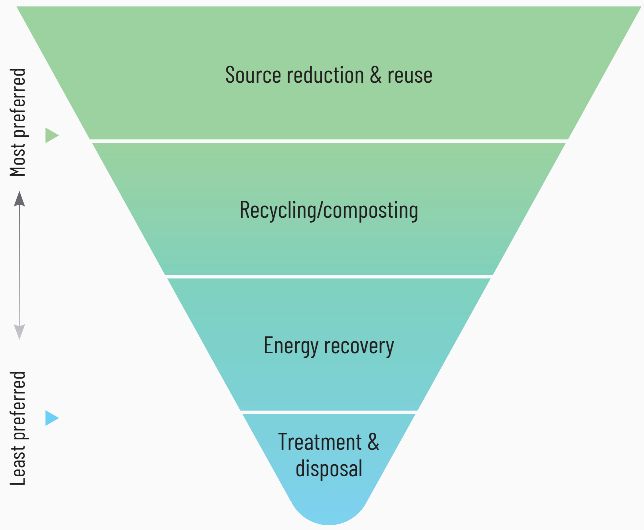
### Chemicals and the international pollution agenda

As highlighted in 2017 at the third session of the United Nations Environment Assembly (UNEA-3), whose theme was "Towards a Pollution-Free Planet", chemicals and waste issues are a key dimension of a broader international and integrated approach to pollution. Chemicals and waste issues were also identified as a key dimension of a broader international and integrated approach to address pollution. Several resolutions were adopted which recognized these linkages, including on lead and on environment and health. The UNEA-3 Declaration requested UNEP to prepare an implementation plan on the issue of a pollution-free planet for consideration by UNEA-4 in 2019. As pointed out in that Declaration, meeting the need for rapid, large-scale and coordinated action against pollution and for moving towards a pollution-free planet is a long-term endeavour. Shaping a pollution-free planet and contributing effectively and equitably to the SDGs requires system-wide transformation and strengthened capacities – global, national and subnational – to act on air, water, soil, marine and coastal pollution and sound management of chemicals and waste (UNEA 2018b).

### Recognizing the interface of chemicals and waste management

For many years the chemicals and waste agendas have been addressed separately, both internationally and in many countries. For example, in Agenda 21 chemicals and waste

**Figure 3.1** **The waste hierarchy, sustainable materials management and the circular economy (adapted from United States Environmental Protection Agency [US EPA] 2017)**




The waste hierarchy strives to achieve similar objectives as the related concepts of sustainable materials management and the circular economy. They have in common the quest to minimize the use of materials and maximize reuse. The sound management of chemicals and waste and innovations in chemistry play a key role in enabling these concepts.

management were covered in separate chapters. However, it has been increasingly recognized that the design and use of safer chemicals and sustainable production processes is essential for reducing releases throughout the life cycles of chemicals and products, including during the reuse, the recycle and disposal stages. These front-of-the-pipe solutions also help ensure that secondary raw materials rechannelled into a circular economy are not contaminated with unwanted hazardous chemicals. In turn, the widely known waste hierarchy (Figure 3.1) focuses on source reduction, reuse and recycling of materials, while energy recovery, waste treatment and waste disposal are seen as least preferred options. The waste hierarchy also emphasizes sustainable material management, resource efficiency and life cycle management. This brief discussion suggests that important aspects of chemicals and waste management are converging, in line with a life cycle management approach.

At the international level, critical progress towards bringing the chemicals and waste management concepts together has been made through SDG Target 12.4, under SDG 12 on sustainable consumption and production, and through including waste in the mandate of the intersessional process on the Strategic Approach and the sound management of chemicals and waste beyond 2020. While GCO-II focuses on the sound management of chemicals and front-of-the-pipe-solutions, the interface with waste management is addressed throughout the GCO-II.

# 4/ Overview of the Global Chemicals Outlook II

In responding to the UNEA mandate to provide options for the implementation of actions to reach relevant SDGs and targets up to and beyond 2020 and, among others, to assess progress towards the 2020 goal, the GCO-II is structured in five parts:

Part I sets the scene by presenting existing and emerging knowledge on production, releases, concentrations and effects of chemicals and waste, as well as the current state of knowledge for estimating the costs of inaction and benefits of action for the sound management of chemicals and waste. Part I also addresses relevant interlinkages, including global resource flows, megatrends, industry sector trends, and the growing complexity of global supply chains.

Part II assesses, to the extent possible, progress towards achieving the sound management of chemicals and waste as called for by the 2020 goal. Given the lack of consolidated data and fragmented indicators and reporting schemes, established through various multilateral treaties and voluntary international instruments, a qualitative approach is taken to assess progress.

Part III assesses progress and outlines opportunities concerning science-based approaches, tools, methodologies and instruments used in the management of chemicals to protect human health and the environment. Over the past decades, valuable lessons have been learned in their practical application, and opportunities have emerged to enhance their effectiveness, simplify their use, and employ them more systematically in all countries. Part III also provides specific suggestions for developing countries and economies in transition to consider in order to benefit from scientific work undertaken in countries with advanced management schemes.

Part IV discusses enabling policies and action that have the potential to scale up innovative solutions to achieve the sound management of chemicals and waste. Advancing sound management and a future chemistry that is fully sustainable requires the engagement of new actors and the shaping of enabling policies and approaches ranging from education reform, support for technology innovation and financing, to innovative business models, sustainable supply chain management and empowerment of citizens, consumers and workers through information and participation rights.

Part V places insights generated in the four previous parts within the context of the 2030 Sustainable Development Agenda, focusing on opportunities for collaborative action to achieve the sound management of chemicals and waste. There is an emphasis on collaborative action to integrate chemicals and waste considerations into key economic and enabling sectors. Part V concludes with a forward-looking discussion with respect to securing commitment by key stakeholders relevant for the future framework on chemicals and waste beyond 2020. It also presents options for the implementation of actions at all levels until and beyond 2020.

# References

American Chemistry Council (2018). Chemical Abstracts Service. http://support.cas.org/about-cas/cas-fact-sheets/registry-fact-sheet. Accessed 15 May 2018.

Anastas, P. and Eghbali, N. (2010). Green chemistry: principles and practice. *Chemical Society Reviews* 39(1), 301-312. https://doi.org/10.1039/b918763b.

Blum, C., Bunke, D., Hungsberg, M., Roelofs, E., Joas, A., Joas, R., Blepp, M. and Stolzenberg, H.-C. (2017). The concept of sustainable chemistry: key drivers for the transition towards sustainable development. *Sustainable Chemistry and Pharmacy* 5, 94-104. https://doi.org/10.1016/j.scp.2017.01.001.

European Environment Agency (2018). Consumption of hazardous chemicals, 7 December. https://www.eea.europa.eu/airs/2018/environment-and-health/production-of-hazardous-chemicals#tab-related-interactive-charts. Accessed 19 January 2019.

Matlin, S.A., Mehta, G., Hopf, H. and Krief, A. (2016). One-world chemistry and systems thinking. *Nature Chemistry* 8(5), 393-398. https://doi.org/10.1038/nchem.2498.

Secretariat of the Strategic Approach to International Chemicals Management (2015). *Report of the International Conference on Chemicals Management on the Work of its Fourth Session*. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/doc/K1606013_e.pdf.

Secretariat of the Strategic Approach to International Chemicals Management, United Nations Environment Programme and World Health Organization (2006). *Strategic Approach to International Chemicals Management: SAICM Texts and Resolutions of the International Conference on Chemicals Management*. Geneva. http://www.saicm.org/Portals/12/Documents/saicmtexts/New%20SAICM%20Text%20with%20ICCM%20resolutions_E.pdf.

United Nations (2002). *World Summit on Sustainable Development, Johannesburg Declaration on Sustainable Development*. 4 September. Johannesburg. A/CONF.199/20. http://www.un-documents.net/jburgdec.

United Nations (2012). United Nations Conference on Sustainable Development, Rio+20. https://sustainabledevelopment.un.org/rio20. Accessed 11 September 2018.

United Nations Environment Assembly of the United Nations Environment Programme (2014). Resolutions and decisions adopted by the United Nations Environment Assembly of the United Nations Environment Programme at its first session on 27 June 2014. http://wedocs.unep.org/bitstream/handle/20.500.11822/17285/K1402364.pdf?sequence=3&isAllowed=y.

United Nations Environment Assembly of the United Nations Environment Programme (2018a). *Environment and Health*. UNEP/EA.3/Res.4. Nairobi. https://papersmart.unon.org/resolution/uploads/k1800154.english.pdf.

United Nations Environment Assembly of the United Nations Environment Programme (2018b). *Implementation Plan "Towards a Pollution-Free Planet"*. UNEP/EA.4/3. Nairobi. http://web.unep.org/environmentassembly/implementation-plan-%E2%80%9Ctowards-pollution-free-planet%E2%80%9D.

United Nations Environment Programme (2010). *Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at Its Tenth Meeting: X/2. The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets*. https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-02-en.pdf.

United Nations Environment Programme (2013). *The 10 Year Framework of Programmes on Sustainable Consumption and Production: Rio+20 Adopts the 10YFP*. https://sustainabledevelopment.un.org/content/documents/944brochure10yfp.pdf.

United Nations Environment Programme and International Council of Chemical Associations (2019). *Knowledge Management and Information Sharing for the Sound Management of Industrial Chemicals*. Montevideo: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/Documents/meetings/OEWG3/inf/OEWG3-INF-28-KMI.pdf.

United States Environmental Protection Agency (2017). Sustainable materials management: non-hazardous materials and waste management hierarchy, 10 August. https://www.epa.gov/smm/sustainable-materials-management-non-hazardous-materials-and-waste-management-hierarchy. Accessed 21 November 2018.

World Business Council for Sustainable Development (2017). *Chemical Sector SDG Roadmap*. https://www.wbcsd.org/Programs/People/Sustainable-Development-Goals/Resources/Chemical-Sector-SDG-Roadmap.

World Health Organization (2017). *Chemicals Road Map: Road Map to Enhance Health Sector Engagement in the Strategic Approach to International Chemicals Management towards the 2020 Goal and Beyond*. http://www.who.int/ipcs/saicm/roadmap/en/.

Zero Discharge of Hazardous Chemicals (2018). Leading the textile, leather and footwear industries towards Zero Discharge of Hazardous Chemicals. https://www.roadmaptozero.com/. Accessed 2 August 2018.

# Key messages for policymakers: a call for more ambitious action at all levels

## The 2020 goal will not be achieved: business as usual is not an option

The findings of the GCO-II indicate that the sound management of chemicals and waste, and minimizing adverse impacts, will not be achieved by 2020. Furthermore, trends data presented in Part I suggest that the projected doubling of the global chemicals market between 2017 and 2030 will increase global chemical releases, exposures, concentrations, and adverse health and environmental impacts unless prevailing gaps to manage chemicals and waste are addressed worldwide. Business as usual is therefore not an option. However, accelerating progress in order to achieve sound management and minimize adverse impacts in the context of the 2030 Agenda is possible under a sustainability scenario. This will require more ambitious, urgent and worldwide collaborative action by all stakeholders and in all countries.

## A comprehensive global framework is needed, with ambitious priorities and coherent indicators

To address gaps, a global framework for the sound management of chemicals and waste beyond 2020 needs to be developed that is aspirational, comprehensive, and creates incentives to foster commitment and engagement by all relevant actors in the value chain. Drawing upon lessons learned from the Strategic Plan for Biodiversity 2011-2020, a global common vision, strategic goals, targets and indicators could facilitate linkages across all relevant agreements and initiatives, and make reporting schemes simpler, country-driven and linked to global targets. Under such a scheme, indicators would need to distinguish between outputs (e.g. adoption of legislation) and impacts (e.g. reduction of adverse impacts from hazardous chemicals).

## Implementation of actions up to and beyond 2020

Responding to the United Nations Environment Assembly (UNEA) mandate to provide options for the implementation of actions to reach relevant Sustainable Development Goals (SDGs) and targets up to and beyond 2020, and based on a review of implementation of the 2020 goal to date, the GCO-II presents a range of options for the implementation of actions (hereinafter referred to as “actions”) to reach relevant SDGs and targets up to and beyond 2020. The identified actions are considered of particular relevance to developing and implementing an international approach for chemicals and waste management beyond 2020. Equally important, they target policy- and decision-makers around the world and from all stakeholder groups in order to generate enhanced commitment for implementation.

The actions are presented under 10 topics which were derived using a back-casting method, imagining a sustainability scenario, where legacy problems are addressed and future legacies are avoided, including through green and sustainable chemistry innovation and sustainable consumption and production. They also cover commitments, already agreed internationally, which require urgent attention and renewed commitment due to implementation gaps. Examples include implementation of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) and the strengthening of basic chemicals and waste management systems.

## 1. Develop effective management systems

Address prevailing capacity gaps across countries, strengthen national and regional legislation using a life cycle approach, and further strengthen institutions and programmes by:

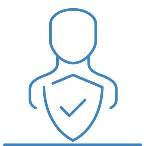
- promulgating, aligning and enforcing legislation and policies, including full implementation of the GHS, promulgating legislation for industrial and consumer products, and taking measures to address illegal international traffic;
- developing national and regional chemicals and waste management action plans and programmes, linked to globally agreed targets and priorities; and
- integrating chemicals and waste considerations into national and sectoral policies (e.g. agriculture, housing, transport and energy) to implement specific SDG targets.

## 2. Mobilize resources

Scale up adequate[1] resources and innovative financing for effective legislation, implementation and enforcement, particularly in developing countries and economies in transition, by:

- scaling up efforts to integrate chemicals and waste management into national and sectoral budgets;
- facilitating adequate external technical assistance, financial support and technology transfer to address issues causing greatest harm, including through new and innovative financing (e.g. fiscal incentives, cost recovery instruments, green bonds, venture capital); and
- strengthening the integrated approach to financing through assessing its effectiveness and renewed commitment across all three components (mainstreaming, industry involvement, and dedicated external financing).

## 3. Assess and communicate hazards



Fill global data and knowledge gaps, and enhance international collaboration to advance chemical hazard assessments, classifications and communication by:

- sharing existing hazard data and assessments globally, and increasing the mutual acceptance of testing data and hazard assessments across countries based on accepted methods and scientific criteria;
- developing a global database of assessed and classified chemicals for information-sharing and promoting harmonization of classifications; and
- setting targets to fill data gaps in order to fully understand globally the hazards of substances in commerce, and assessing progress.

1 To facilitate better understanding of the term "adequate" in this context, further analysis and international dialogue are needed on certain topics such as sustainability of funding.

## 4. Assess and manage risks

Refine and share chemical risk assessment and risk management approaches globally to promote safe and sustainable use of chemicals and address emerging issues throughout the life cycle by:

- sharing knowledge on existing risk assessment and management approaches and tools (e.g. exposure scenarios) more widely;
- further developing and refining exposure, risk assessment and life cycle assessment (LCA) methods; and
- taking into account and benefiting from opportunities for accelerated and effective risk management, such as placing the burden of proof on producers, advancing informed and non-regrettable substitution of chemicals of high concern, and using generic risk-based approaches, when possible.

## 5. Use life cycle approaches

Advance widespread implementation of sustainable supply chain management, full material disclosure, transparency and sustainable product design by:

- promoting wide implementation of corporate sustainability and sustainable procurement policies;
- developing harmonized approaches across sectors to share chemical information and to advance full material disclosure across supply chains, including chemical-intensive industry sectors and the recycling/waste sector;
- strengthening collaboration by all actors in the supply chain in designing and using safer chemicals and sustainable products; and
- promoting the integration of chemicals and waste considerations into corporate sustainability metrics and reporting.

## 6. Strengthen corporate governance

Enable and strengthen chemicals and waste management aspects of corporate sustainability policies, sustainable business models, and reporting by:

- encouraging private sector frontrunner action to further develop voluntary standards that exceed basic compliance, and reviewing their effectiveness through interested stakeholders;
- promoting sustainable business models, such as Chemical Leasing and eco-industrial parks; and
- enhancing systematic use by investors of corporate sustainability and chemical footprint reporting, covering chemicals and waste management performance.

## 7. Educate and innovate

Integrate green and sustainable chemistry in education, research, and innovation policies and programmes by:

- reforming chemistry curricula in tertiary, secondary, primary and professional education;
- scaling up research initiatives, and technology innovation policies and programmes, that advance green and sustainable chemistry, particularly for start-up companies; and
- facilitating a better global understanding of green and sustainable chemistry concepts.

## 8. Foster transparency

Empower workers, consumers and citizens to protect themselves and the environment by:

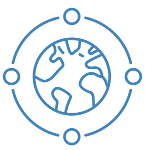
- disclosing robust and understandable information about hazardous chemicals in the supply chain to workers, consumers, citizens and communities;
- scaling up innovative programmes and technology applications to facilitate a better understanding by individuals of chemical and waste risks, and engaging citizens in data collection through citizen science;
- promoting and supporting meaningful and active participation by all actors of civil society, particularly women, workers and indigenous communities, in regulatory and other decision-making processes that relate to chemical safety; and
- taking action so that citizens have ready access to justice.

## 9. Bring knowledge to decision-makers

Strengthen the science-policy interface and use of science in monitoring progress, priority-setting (e.g. for emerging issues), and policymaking throughout the life cycle of chemicals and waste by:

- taking steps to harmonize scientific research protocols (e.g. for biomonitoring);
- developing science-based criteria to identify emerging issues at the international level, taking into account harm (e.g. using health impact information) and monitoring their implementation;
- providing research funding to fill identified gaps and priorities; and developing a study on the global costs of inaction, and benefits of action, on chemicals and waste management, comparable to the Stern Review on The *Economics of Climate Change*; and
- developing and improving institutional mechanisms to improve knowledge generation and management.

## 10. Enhance global commitment



Establish an ambitious and comprehensive global framework for chemicals and waste beyond 2020, scale up collaborative action, and track progress by:

- developing an aspirational, overarching and widely owned global framework that encourages engagement by all relevant stakeholders; and developing global targets, milestones and indicators that distinguish between outputs and impacts;
- providing opportunities for sharing internationally, and for input or peer reviews, action plans and roadmaps by stakeholders under a beyond 2020 framework;
- considering how corporate sustainability metrics and reporting can play a stronger role in measuring progress in a beyond 2020 framework; and
- monitoring, tracking and reviewing collective action and progress and making adjustments in regard to ambition, as needed.

### Results-based stakeholder roadmaps, mutual reviews and accountability beyond 2020

The period up to the conclusion of the intersessional process, by 2020, provides a brief but critical window in which to develop an ambitious and comprehensive global framework – as well as to increase engagement by all stakeholders. What mechanisms could facilitate the needed commitment, ownership, mutual accountability and collective monitoring of progress towards achieving the sound management of chemicals and waste?

To facilitate the success of the global collaborative framework on chemicals and waste, all relevant stakeholders could be challenged to make voluntary yet clear public commitments and pledges, specifying concrete plans and steps to be taken. One option is that countries and all relevant stakeholders could develop, implement and share, internationally, results-based action plans and roadmaps to implement the 2030 Agenda from a chemicals and waste perspective. Action plans and roadmaps could be prepared in a collaborative manner by countries, industry sectors (e.g. the chemicals industry, chemical-intensive downstream sectors, retailers, the recycling industry), civil society organizations, the Inter-Organization Programme for the Sound Management of Chemicals (IOMC), academia and others. They could also be prepared at the thematic level and involve several stakeholders (e.g. for an initiative to fill data gaps in order to understand the hazard potential of chemicals).

There are examples of roadmaps already prepared which address the sound management of chemicals and waste management, or certain aspects of it. They include the World Business Council for Sustainable Development (WBCSD) Chemical Sector SDG Roadmap and the WHO Chemicals Road Map. This proposed roadmap approach would be compatible with, and take into account, experience gained in other international forums, such those concerned with climate change. These have evolved to include a more flexible, yet results-oriented and mutually accountable, approach to compiling commitments and action taken, with reviews taking place internationally to track process and adjust ambition levels, as appropriate.

Collectively, these action plans and roadmaps would provide an indication of commitments and allow assessing the extent to which collaborative action succeeds in making the progress needed to achieve the sound management of chemicals and waste. Commitments and progress could be made available to the public in order to monitor progress. Stakeholders could pledge and showcase their action plans and roadmaps within the beyond 2020 framework and benefit from the input of other stakeholders (which might take different forms, such as peer review). Pledges could be reviewed globally against agreed goals and targets, with adjustments made as appropriate. Frontrunners would be rewarded, and space would be given to key actors to step up and provide leadership.

# I. The evolving chemicals economy: status and trends relevant for sustainability

## About Part I

A wealth of economic and scientific information relevant to the sustainability of the chemical industry has been generated since the GCO-I. Part I of the GCO-II presents existing and emerging economic and scientific knowledge and, where possible, trends in regard to a range of topics of relevance for chemicals and waste management. In conjunction with Parts II and III, Part I provides information on progress made towards the implementation of the 2020 goal, focusing on impact indicators. Findings indicate that the international community is not on track to minimize the adverse impacts of chemicals and waste on human health and the environment.

The overarching structure of Part I is as follows: Chapters 1 and 2 provide an overview of the global chemical industry and the production and sales of chemicals. Part I then proceeds by providing knowledge on chemical releases and concentrations, followed by a discussion of the effects of chemicals on human health and the environment, including the cost of inaction and benefits of action related to sound management. As chemical production and sales are heavily affected by, and linked to, global megatrends as well as trends in chemical-intensive industry sectors, these topics are discussed in a dedicated chapter. Special attention is also given to the increasing complexities associated with chemicals in products and global supply chains and to circularity challenges. Throughout Part I, challenges encountered in collecting coherent global data, developing baseline knowledge, identifying trends and documenting knowledge gaps are highlighted.

## Contents

1/ The chemical industry 24

2/ Trends in production and sales of specific chemicals 41

3/ Megatrends and chemical-intensive industry sectors: risks and opportunities 61

4/ Global supply chains, chemicals in products, and circularity 78

5/ Chemical pollution: emissions, releases and wastes 92

6/ Concentrations of chemicals in the environment and humans 120

7/ Environmental, health and social effects of chemicals 145

8/ The economic benefits of action and the costs of inaction 164

References 176

# 1/ The chemical industry

## Chapter Highlights

Between 2000 and 2017 the global chemical industry's production capacity almost doubled, from about 1.2 to 2.3 billion tonnes.

If pharmaceuticals are included, global sales totalled US (United States) dollars 5.68 trillion in 2017, making the chemical industry the second largest manufacturing industry in the world.

Sales are projected to almost double from 2017 to 2030.

In emerging economies the sales, production volume and production capacity of the chemical industry have grown and are projected to continue growing rapidly, especially in China.

The chemical industry turns large amounts of resources into chemical products, including oil and natural gas used as primary feedstocks.

The chemical industry is going through a period of mergers, acquisitions and other types of restructuring.

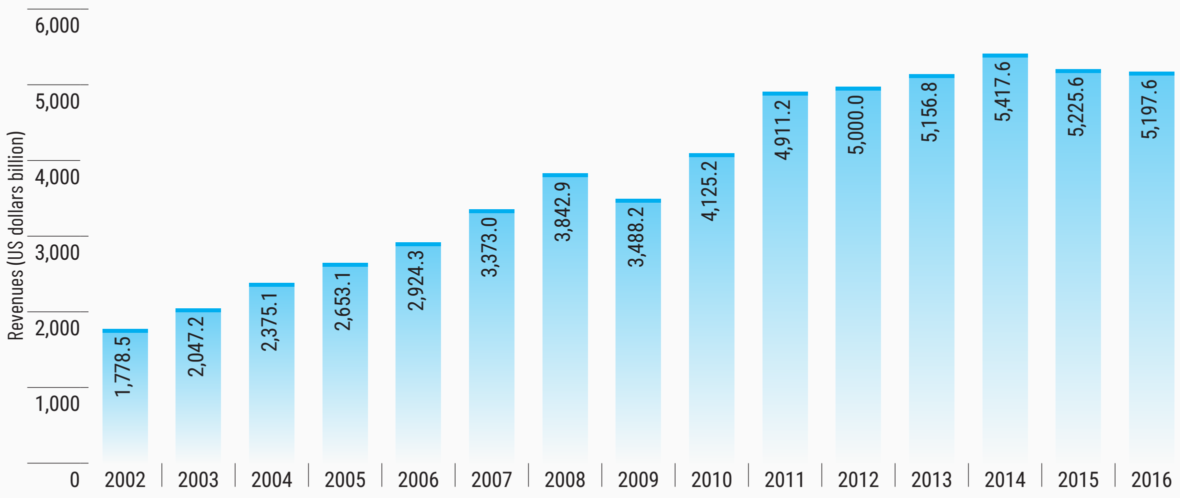
This chapter provides an overview of the global chemical industry. It starts by presenting available data on the status and historic trends in the sales, production volume and production capacity of the chemical industry, followed by an overview of related forecasts. The chapter proceeds by examining the industry's role as a major component of the global system of production and consumption, including its global value chain and its role in global resource flows. The chapter closes by exploring how the chemical industry is restructuring and by briefly examining important trends in research and development.

## 1.1 The chemical industry: status and historic trends

### The chemical industry is one of the world's largest industries

Total chemical industry revenues have a long history of steady growth, at 4-4.5 per cent, although in the past several years there has been some flattening out (Figure 1.1). The growth rate was 4.6 per cent in 2017. Global sales in 2017 are estimated at US dollars 3.47 trillion, excluding pharmaceuticals (European Chemical Industry Council [Cefic] 2018). If pharmaceuticals are included, global sales in 2017 were an estimated US dollars 5.68 trillion (American Chemistry Council [ACC] 2018). This makes the chemical industry the second largest manufacturing industry in the world (International Labour Organization [ILO] 2018).

**Figure 1.1** Total chemical industry revenues, 2002-2016 (US dollars billion) (based on ACC 2017)

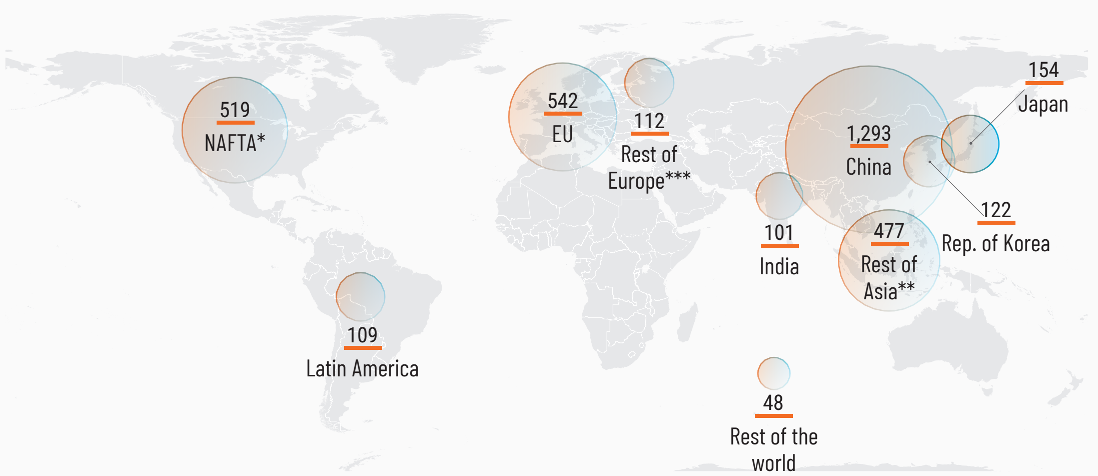



## Asia has rapidly increased its market share and China now has the largest chemical industry

Throughout much of the 20th century the chemical industry was based largely in Europe, North America and Japan. Since the 1970s it has expanded internationally, with much new investment occurring in Asia and the Middle East (Budde *et al.* 2017). Faced with the need to increase capacity to meet global demand in the 1990s, growth was driven by investments from multinational companies, based in Organisation for Economic Co-operation and Development (OECD) countries, in production facilities in non-OECD countries. Since 2000 domestic chemical companies, particularly in China and the Middle East, have become increasingly dominant producers. Companies in India are also rapidly expanding their market share.

Today Asia is the largest chemical producing and consuming region (Figure 1.2). China has the world's largest chemical industry, with annual sales of around euros 1,293 billion or about 37 per cent of global sales. Its sales are larger than those of the next nine counties combined.

**Figure 1.2** Chemical sales by geographic region, 2017 (EUR billion) (adapted from Cefic 2018, p. 6)




* North American Free Trade Agreement
** Asia excluding China, India, Japan and South Korea
*** Rest of Europe covers Switzerland, Norway, Turkey, Russia and Ukraine


The European Union (EU) ranks second with a market share of about 16 per cent, followed by the United States with about 13 per cent. In 2017 the BRICS countries (Brazil, Russia, India, China and South Africa) accounted for around 44 per cent of all chemical sales (Cefic 2018). As of 2016, four of the top 10 largest chemical companies were based in Asia or the Middle East (Tullo 2017a).

### Asia and the Middle East have experienced the strongest growth in production volume and capacity

In terms of production volume, Europe and North America stagnated between 2000 and 2017. During the same period China, the Middle East and India experienced rapid growth at a compound annual growth rate (CAGR) of 11.8, 8.5 and 7.6 per cent, respectively (Cayuela and Hagan 2019) (Figure 1.3).

**Figure 1.3** Growth in production volume, 2000-2017 (adapted from Cayuela and Hagan 2019)

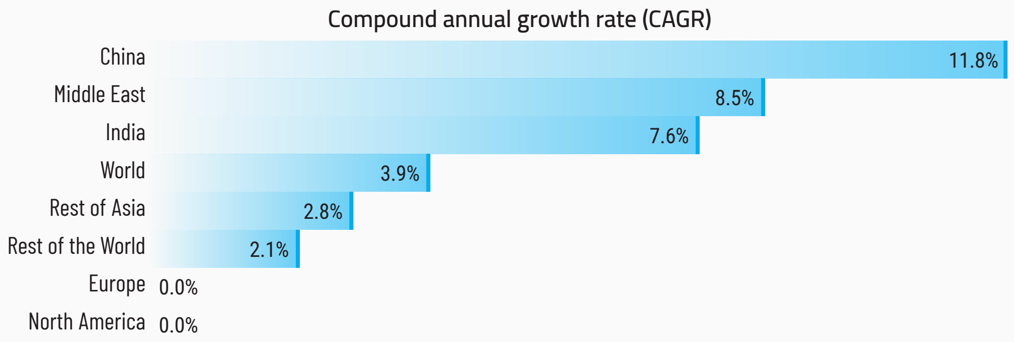
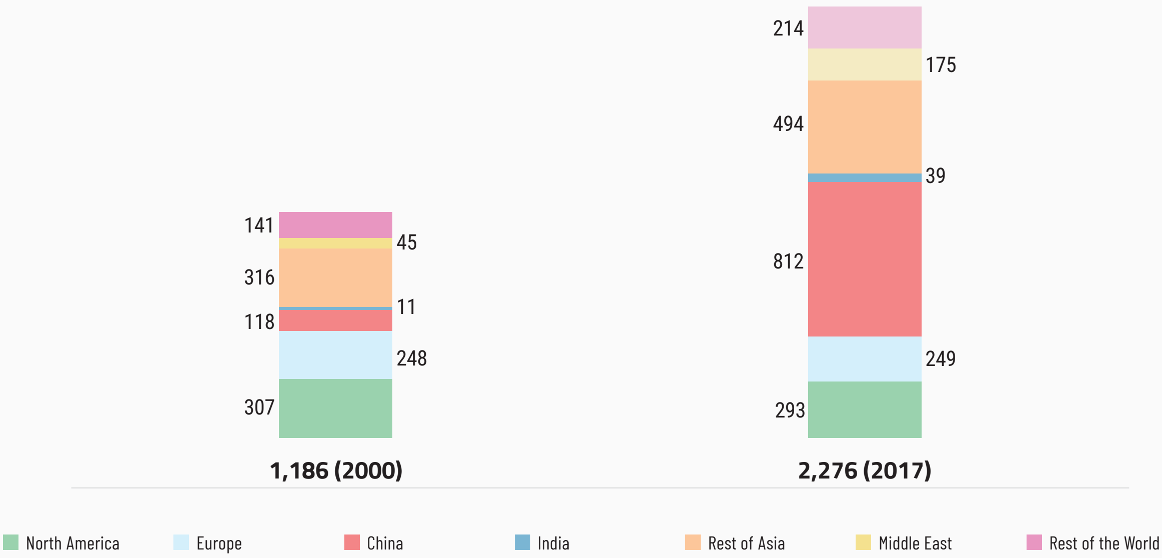


**Figure 1.4** Global chemical industry capacity growth in million tonnes, 2000-2017 (adapted from Cayuela and Hagan 2019)




The production capacity of the global chemical industry almost doubled between 2000 and 2017 to reach some 2.3 billion tonnes (Cayuela and Hagan 2019), suggesting continued future increases in the volume of chemicals produced. Growth in production capacity has been particularly rapid in China and India (Figure 1.4).

### International trade in chemicals has also been increasing rapidly

As the industry and its markets have grown, so has international trade in chemicals. The value of China's exports of chemicals has increased by 15 per cent since 2013, the year the first *Global Chemicals Outlook* was published (United Nations Comtrade 2018). Chemicals and products containing chemicals are traded in large volumes around the world. Exports (excluding intra-EU exports) reached a global value of around US dollars 748 billion in 2017 (World Trade Organization [WTO] 2018). In terms of export value, the EU is the largest chemicals exporting region (around 20 per cent of global exports), followed by the United States (around 10 per cent) and China (around 7 per cent). As regards import value, the United States (around 10 per cent of global imports) is closely followed by the EU (around 10 per cent) and China (around 9 per cent) (WTO 2018).

## 1.2 The chemical industry: forecast and outlook

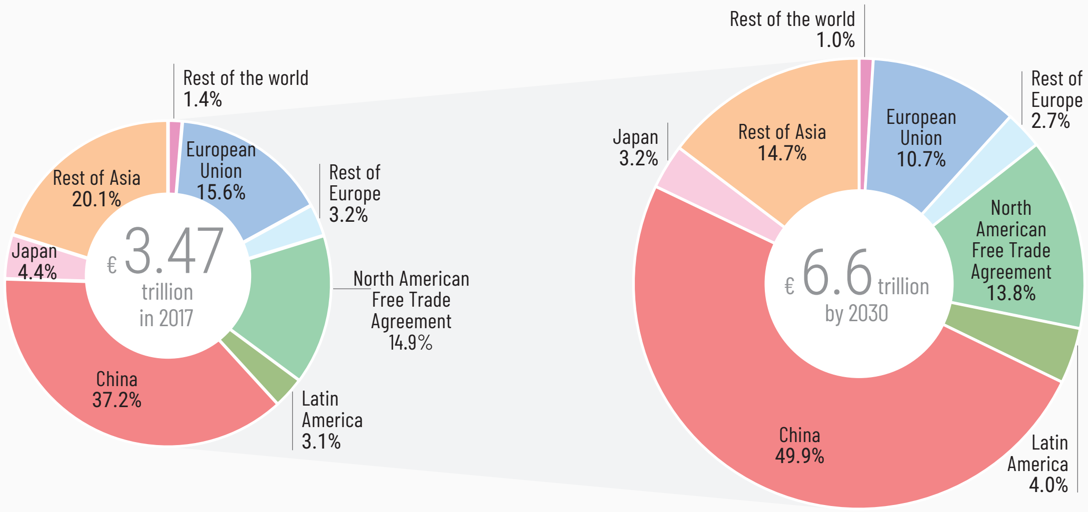
### Growth in sales is expected to continue in the medium and long term

Growth in sales is expected to continue, although more slowly than in the past decade. While estimates vary according to the period selected for analysis, some forecasts show world chemical sales almost doubling between 2017 and 2030 to reach euros 6.6 trillion (Cefic 2018). By 2030 China's share of the global market is projected to increase to almost 50 per cent (Cefic 2018) (Figure 1.5). According to the OECD (2019), the value of the global production of chemical products will reach almost US dollars 22 trillion by 2060.

### Growth rates are expected to be strongest in Asia, Africa and the Middle East

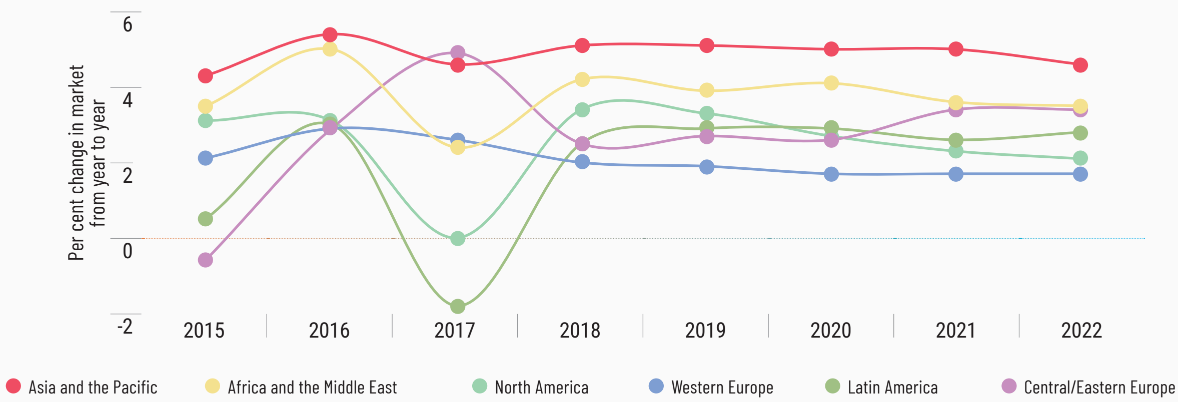
It is expected that future industry growth will be driven mainly by emerging markets, where gains are likely to be 6-10 per cent per year compared with 2-3 per cent in higher-income economies. Growth in the Asia-Pacific region, Africa and the Middle East is projected to be strongest in almost every year until 2022 (ACC 2017) (Figure 1.6).

**Figure 1.5** Projected growth in world chemical sales, 2017-2030 (adapted from Cefic 2018, p. 34)




Global chemical sales (excluding pharmaceuticals) are projected to grow from euros 3.47 trillion in 2017 to euros 6.6 trillion by 2030. Asia is expected to account for almost 70 per cent of sales by then.

**Figure 1.6** Projection of annual production growth in the chemical industry by region, 2015-2022 (per cent change per year) (based on ACC 2017)






While production of chemicals is projected to grow in each region, annual growth rates are highest in regions with developing countries and emerging economies, particularly in Asia-Pacific, Africa and the Middle East.

## 1.3 The chemical industry in the global system of production and consumption

### Value chain of the chemical industry

The global value chain of the chemical industry and its products extends from the extraction of raw materials to the use and reuse of industrial and consumer products. A simplified representation of this value chain is shown in Figure 1.7. At the core of the chemical industry are huge, highly capitalized installations where millions of tonnes of basic chemicals are produced as feedstocks for the thousands of chemicals that make up the chemical market. However, the industry is


increasingly diversifying into high-technology sectors such as biotechnology, nanotechnology and new materials, which have applications, for example, in health care, consumer goods, manufacturing, communication, transportation and environmental protection (Valencia 2013; Sarathy *et al.* 2017).

Focusing on the first three of the steps in Figure 1.7 and examining, in particular, chemical manufacture, processing or refining in more detail, the global value chain of the chemical industry can be divided into five key segments, as shown in Figure 1.8 (Bamber, Frederick and Gereffi 2016). In a first step feedstocks – such as natural gas and minerals – are processed into high-volume and low-value "bulk" chemicals. These are conventionally produced in high-capacity refineries and milling facilities with high capital investment costs. Intermediate chemicals are generally developed for further use in production or manufacturing processes (e.g. dyes for paint production). Specialty chemicals are higher in value and are designed to fulfil specific functions. Given the relatively lower investment needed, a larger number of smaller companies can operate in this segment. Chemical processing and product manufacturing in downstream facilities is connected to innumerable product manufacturers in sectors such as agriculture, construction and electronics. The various segments may span a number of countries across the world.

## The global value chain of the chemical industry is complex and highly integrated globally

The linkages among chemical manufacturers and their suppliers and downstream customers are often complex and heavily integrated. Chemical supply chains can be long. Customers may be global, often located in several countries or on different continents. In addition, a change in market conditions for one high-volume chemical can have important economic implications for many other chemicals, including those co-produced as by-products and others manufactured downstream. For example, production of polyethylene (PE) (the world's most commonly used plastic) generates co-products used to make polystyrene (PS) and polyester. Reduced use of plastic shopping bags and other

**Figure 1.7** Value chain of the chemical industry: from extraction to finished products

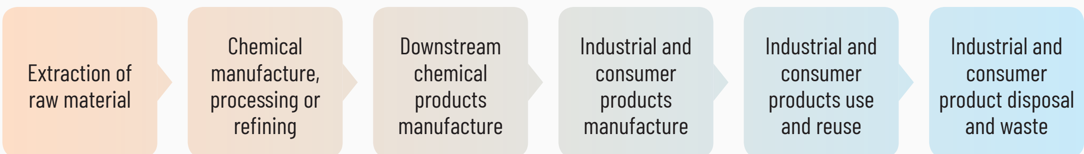
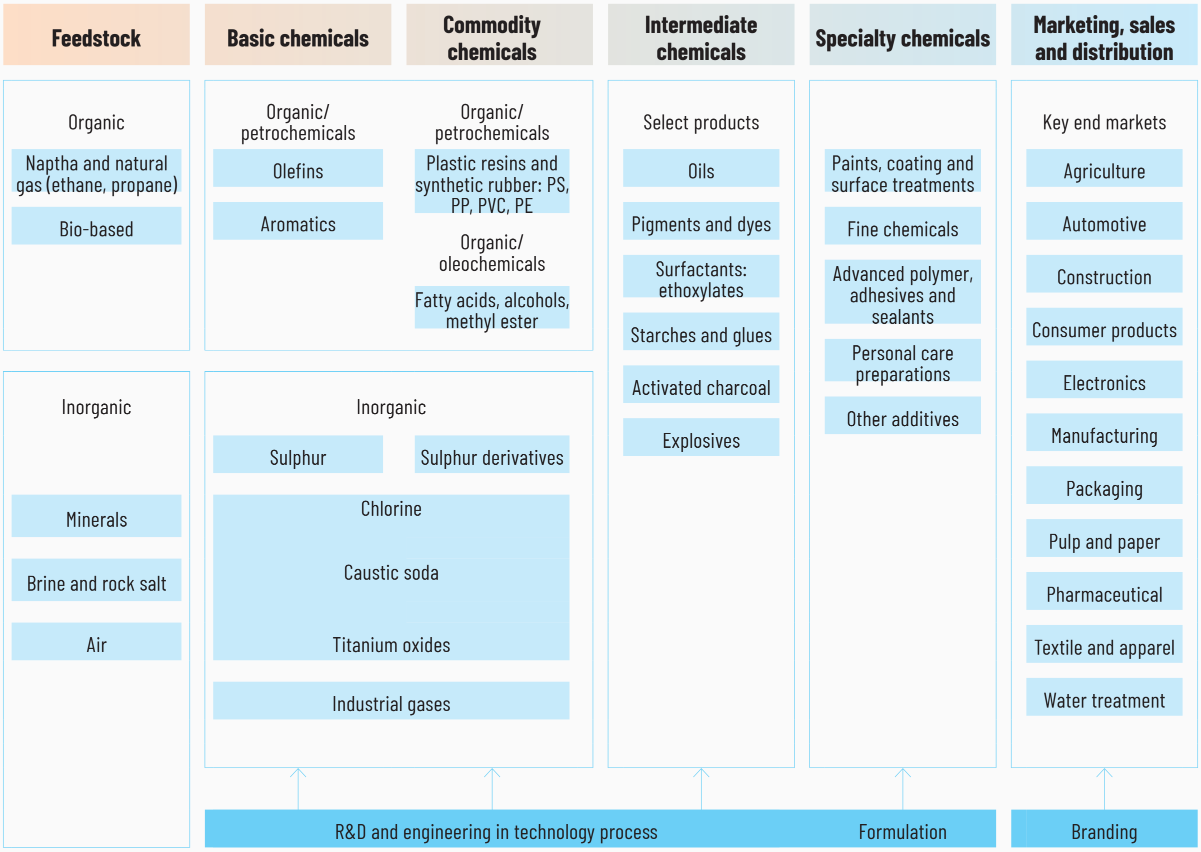


**Figure 1.8** Chemical segments in the global value chain (Based on Bamber, Frederick and Gereffi 2016, p. vii)




polyethylene objects affects not only the market for polyethylene itself, but also the availability and price of polystyrene and polyesters.

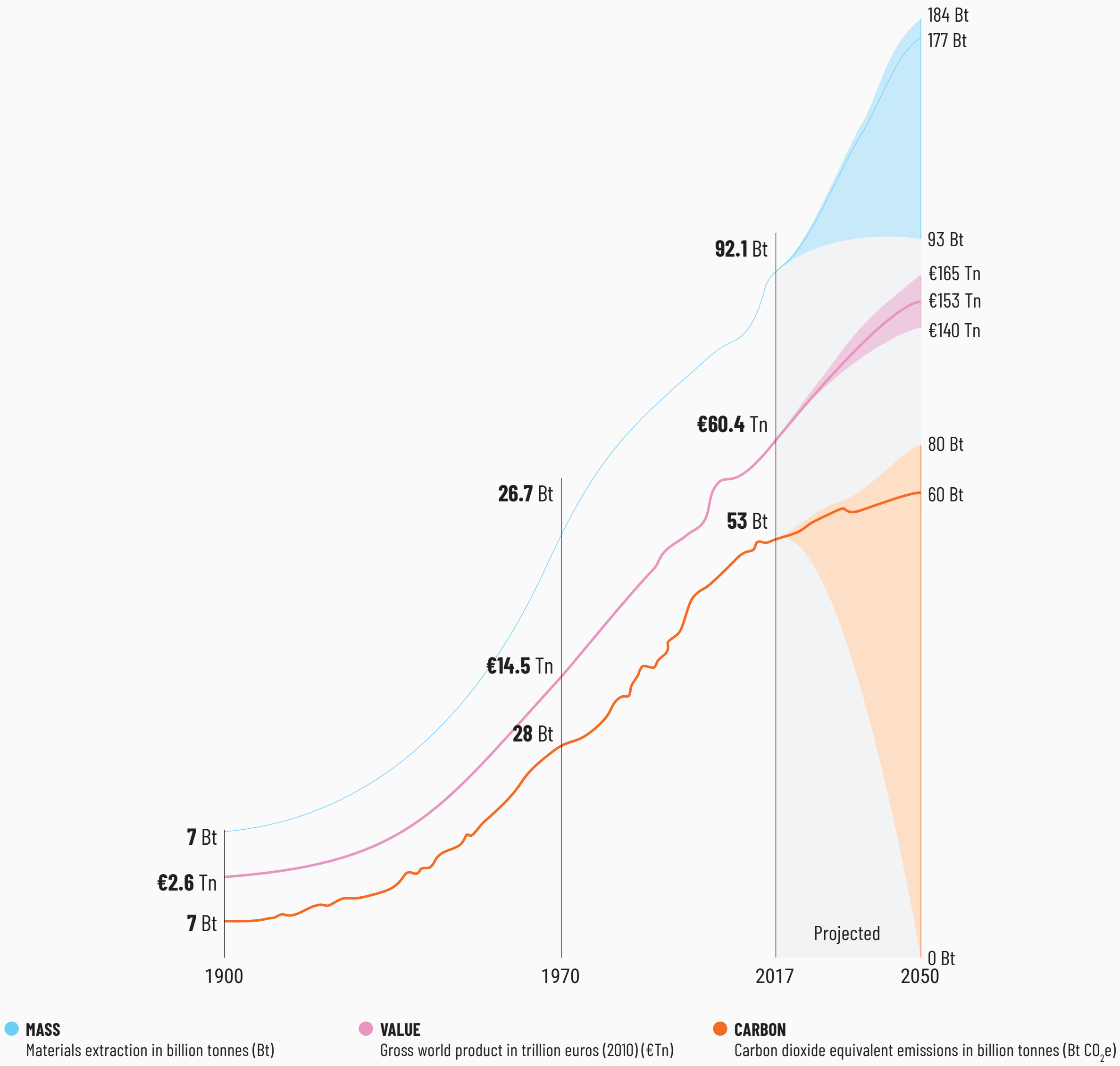
## Emerging economies are strengthening their position in higher-value markets

Value chains are governed by global markets that regulate the processing, distribution and formulation of chemicals. The liberalization of these markets, combined with production, logistics and information technology innovations, have decentralized chemical production and decreased costs (Nicita *et al.* 2013). These developments have presented opportunities for low-income countries to participate in the globalized market, e.g. through the production and export of basic chemicals which are then further synthesized and polymerized elsewhere. While the chemical industries in most emerging economies are still focused on producing bulk chemicals, some seek to move up the value chain by strengthening their position in the market for intermediates and specialty products. A study on the role of the Philippines in the global chemical industry found that in 2014 basic and commodity chemicals accounted for more than two-thirds of chemical exports (Bamber, Frederick and Gereffi 2016). However, some firms had started to enter the market for intermediate and specialty chemicals. Emerging countries also play a growing role in manufacturing products for key end markets which are chemical-intensive.

## The chemical dimension of global resource flows

Manufactured chemicals are an integral part of the sourced, generated and stored materials flowing through the global economy. According to the International Resources Panel's *Global Resources Outlook* 2019 (Oberle *et al.* 2019), approximately 92 billion tonnes of materials are estimated to have been extracted globally in 2017. The *Outlook* assumes that under a historical trends scenario, this will reach 190 billion tonnes

**Figure 1.9** **Trends in materials extraction, financial value creation and greenhouse gas emissions (1900-2050) (adapted from de Wit *et al.* 2019, p. 11)**



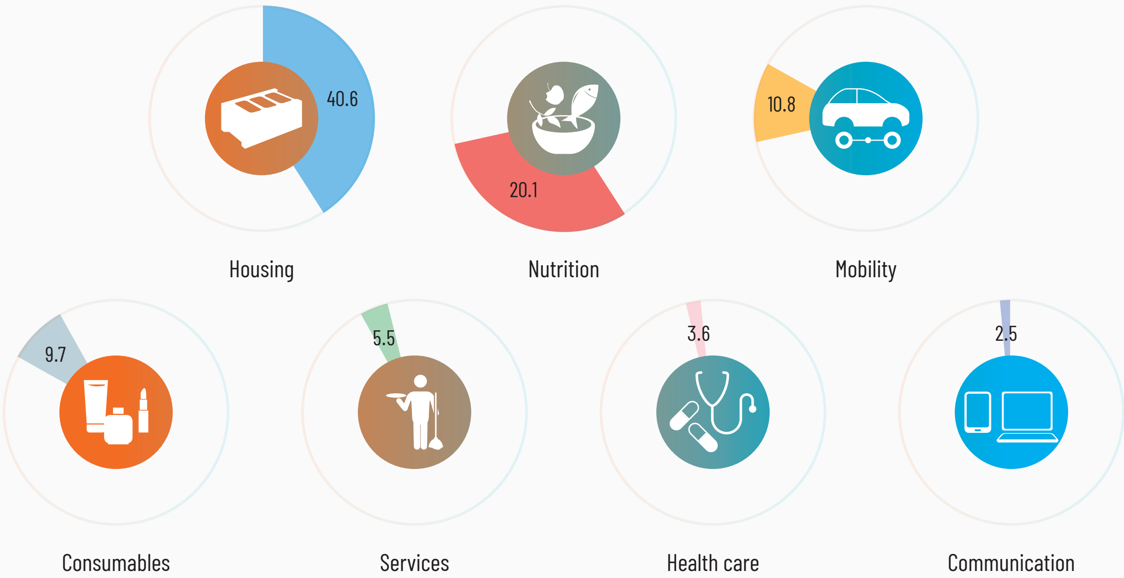

To date, global materials extraction has grown roughly in line with global economic growth and greenhouse gas emissions.

by 2060. The 2019 *Circularity Gap Report* notes that materials use has almost tripled since 1970 (Figure 1.9).

The extraction of resources is driven by societal needs (Figure 1.10). Each of these sectors is chemical-intensive in terms of both production processes and products, ranging from asbestos used in steel beams, to pesticides in agriculture, to heavy metals in batteries, to parabens in cosmetics. To date, the overarching formula has been that as societal needs increase, so does consumption of chemicals.

The chemical industry plays an important role in turning raw materials and feedstocks into valuable products. It therefore performs a key function in the global system of production and consumption and is one of the drivers of resource extraction, together with chemical-intensive sectors. Production of petrochemicals (e.g. styrene), consumer chemicals (e.g. detergents), specialty chemicals (e.g. dyes), basic inorganics (e.g. fertilizers) and polymers (e.g. plastics) relies on the extraction of fuels and minerals (Fantke and Ernstoff 2018). Researchers have mapped the magnitude of the chemical

**Figure 1.10** The global material footprint: extracted resources by key societal needs and consumables, 2015 (billion tonnes) (based on de Wit *et al.* 2019, p. 19)




Six key societal needs and consumables represent the largest material footprint globally: housing and infrastructure (ca. 44 per cent), nutrition (ca. 22 per cent), mobility (ca. 12 per cent), consumables (ca. 11 per cent), services (ca. 6 per cent), health care (ca. 4 per cent) and communication (ca. 3 per cent). Each of these sectors is chemical-intensive in terms of both production processes and products, which range from asbestos used in steel beams, to pesticides in agriculture, to heavy metals in batteries, to parabens in cosmetics.

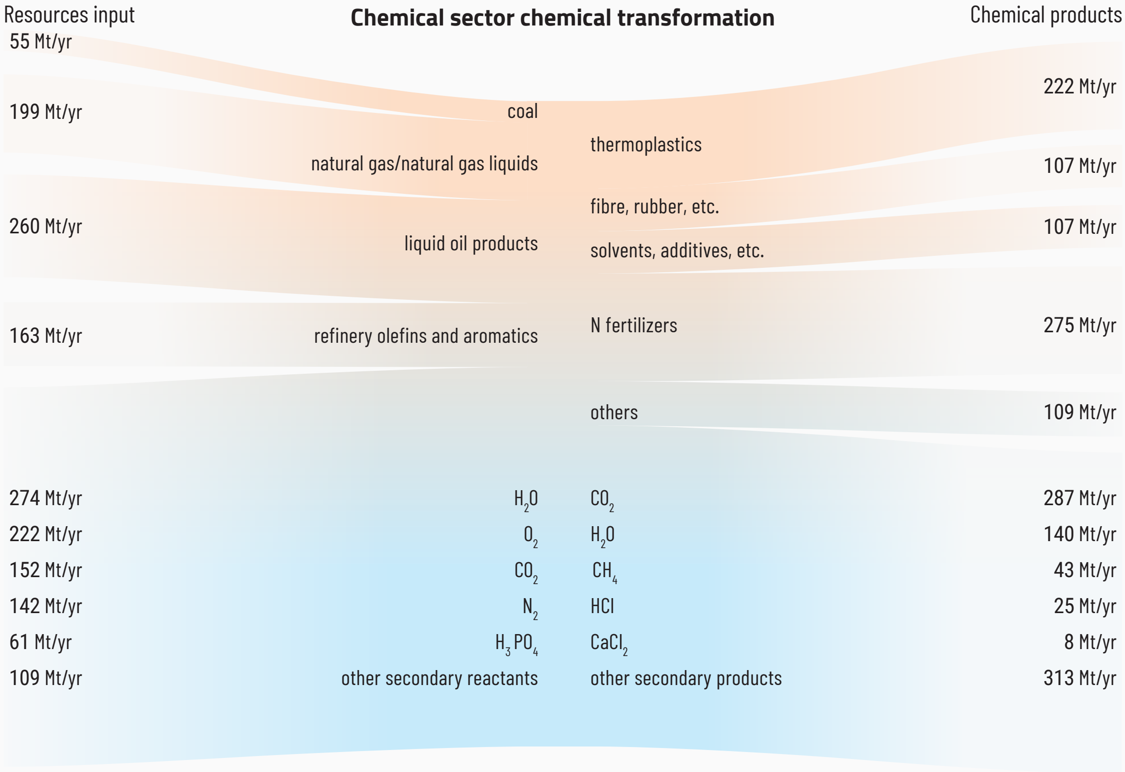
sector's material resources flows (Figure 1.11). In a single year (2015) almost 1,700 million tonnes of feedstocks and secondary reactants were used in this sector to produce 820 million tonnes of chemical products, while also generating almost the same amount of by-products.

The transformation of feedstocks and reactants into chemical products and secondary products also has a qualitative dimension. In the process of chemical production new compounds are created, in some cases with new or increased hazards. Chlorine chemistry, for example, turns basic feedstocks such as salt and water, together with other chemicals, into useful products such as water purification chemicals. At the same time, chlorine and many chlorine derivatives, as well as chemicals used in related production processes (e.g. asbestos or mercury), are hazardous and need to be well-managed.

### The global chemical industry consumes a large amount of energy

The chemical industry is the world's largest industrial energy consumer. It is also the third largest industrial emitter of $CO_2$ (Levi and Cullen 2018). The industry accounts for approximately 10 per cent of global energy demand, or 30 per cent of total industrial energy demand, worldwide. Of the industry's total energy input, 58 per cent is consumed as feedstock. However, this demand is highly concentrated (International Energy Agency [IEA], International Council of Chemical Associations [ICCA] and Society for Chemical Engineering and Biotechnology [DECHEMA] 2013). For example, the manufacture of some 26 basic chemical compounds (including nitric acid, ethylene, propylene and butadiene) within the European chemical industry consumes some 75 per cent of the industry's total energy use and is responsible for more than 90 per cent of its greenhouse gas (GHG) emissions (Boulamanti and Moya 2017).

**Figure 1.11** Resource extraction by the chemical sector and related chemicals production, 2013 in millions of tonnes (Mt) (adapted from Levi and Cullen 2018, p. 1725)



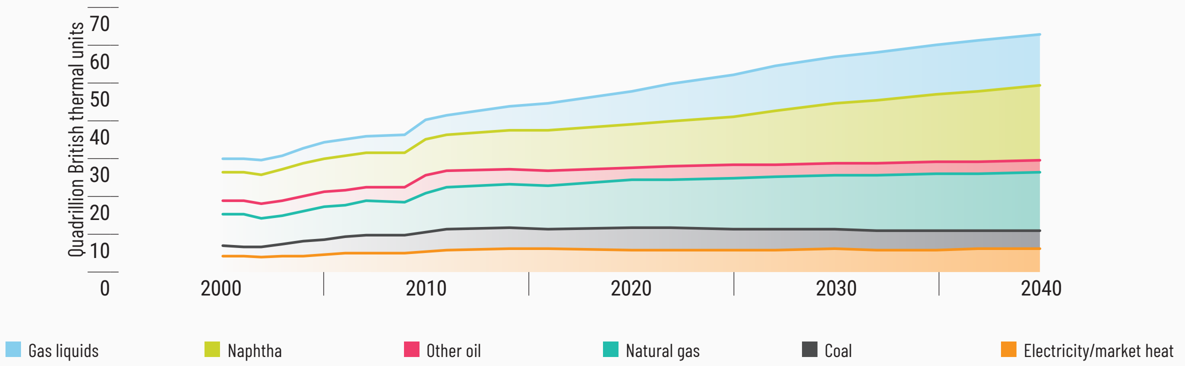

In 2013 around 513 million tonnes (Mt) of fossil fuels and around 163 Mt of olefins and aromatics were used as feedstock by the chemical industry. In addition, it used almost 1,000 Mt of secondary reactants (water, oxygen, carbon dioxide [$CO_2$], nitrogen and phosphoric acid). These feedstocks were transformed through various stages of upstream and downstream production to produce 820 Mt of chemical products. Around 34 per cent of this output consists of nitrogen fertilizers and around 27 per cent of thermoplastics. The chemical industry also generated 815 Mt of secondary products, including 140 Mt of methane and 287 million tonnes of $CO_2$.

The chemical industry has made efforts to reduce energy consumption and to invest in energy conservation. Investments have focused on redesigning catalytic processes; improving membranes and separation processes; improving efficiencies in production, storage and transport; better tailoring of heating and cooling; use of lower-carbon fuels; and integrating carbon capture and storage (IEA, ICCA and DECHEMA 2013). Nevertheless, its energy consumption continues to grow (Wernet *et al.* 2011; Darkow and von der Gracht 2013).

## Chemical production continues to rely on oil, natural gas and coal

Fossil fuels (oil, gas and coal) are the feedstocks for basic petrochemicals and the source of the large amount of energy needed to manufacture most chemical products (Figure 1.12). Moreover, several of the world's largest chemical producers are owned by fossil fuel producers. The increase in the amount of available, low-cost natural gas has boosted chemical production in several global regions. Shale gas can now be obtained economically using horizontal drilling and hydraulic fracturing ("fracking") technologies. In the United States, which currently produces almost all the natural gas it uses, this technology has encouraged significant new investments in petrochemical capacity (ACC 2013; Center for International Environmental Law n.d.).

**Figure 1.12** Feedstocks for chemical production, 2000-2040 (quadrillion British thermal units [BTUs]) (adapted from Exxon Mobil 2018)

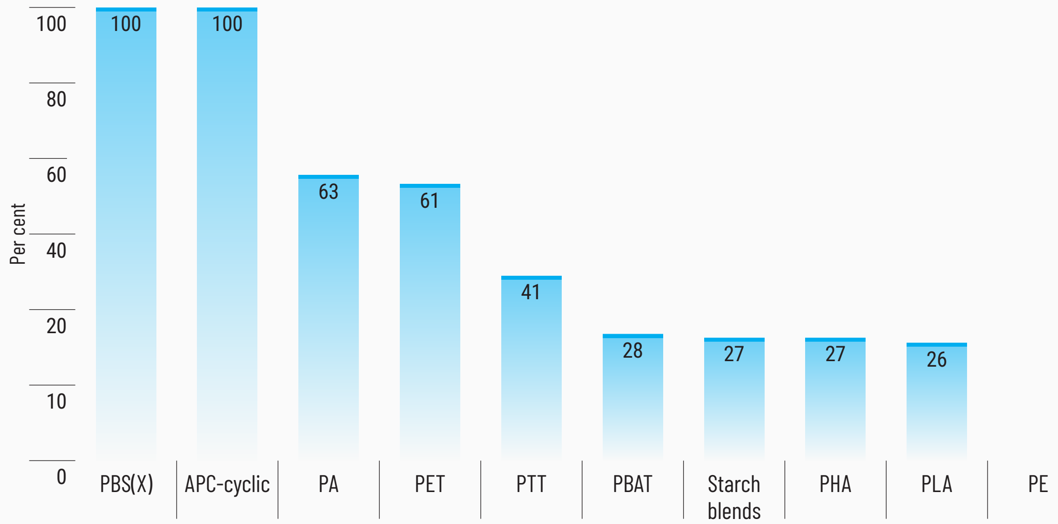



## Use of renewable and bio-based feedstocks is increasing

While oil and natural gas will continue to provide the energy and primary feedstocks for the industry, sustainability concerns are driving a growing shift towards the use of bio-based and renewable resources as feedstocks. Some chemicals have long been produced from renewable resources. Examples are the lactic acid esters used as a substitute for chlorinated solvents in cleaning and degreasing agents, and corn used as the basis for a significant share of the ethanol used as motor fuel. Today many high-value polymers and industrial enzymes can be produced from biological feedstocks (Bomtempo *et al.* 2017). The feedstocks used to produce bio-based chemicals have recently expanded from edible sugars to inedible and lignocellulosic biomass. Such a shift could reduce the need for crops as feedstocks in favour of wood pulp. However, significant land use would still be needed for large-scale production. Progress has also been made in the bioprocessing of microbial production of chemicals from renewable feedstocks (Kawaguchi *et al.* 2016).

The next two decades are likely to see significant growth of the global bio-based chemical industry. The market for bio-based chemicals is expected to grow from 2 per cent of the total chemical market to 22 per cent by 2025. While the global polymer market is predicted to exceed US dollars 450 billion by 2025, the share of bio-based chemicals is expected to increase to 10-20 per cent of that market (United States Department of Agriculture 2008).

**Figure 1.13** Share of Asian bio-based polymer production capacity in global production, 2016 (per cent) (adapted from Baltus 2017, cover page)




### Asia is the largest producer of bio-based polymers

By 2016 global capacity for bio-based polymers production reached 2.4 million tonnes, with more than 45 per cent of the most important bio-based polymers produced in Asia (primarily in China, Japan, Malaysia, the Republic of Korea, Taiwan and Thailand) (Figure 1.13). Global capacity for bio-based polymers production is expected to reach 3.6 million tonnes in 2021, with nearly 52 per cent installed in Asia (Baltus 2017).

## 1.4 Chemical industry structure and organization

The chemical industry is made up of several hundred highly integrated multinational corporations and thousands of small and medium-sized chemical processing and compounding enterprises. In some industry segments, such as basic chemicals and pharmaceuticals, there are a few very large dominant firms. On the other hand, the specialty chemical segment is highly fragmented, with hundreds of sub-segments and thousands of producers distributed widely around the world. In the last two decades the chemical industry has undergone significant transformations, triggered by the entrance of China and the Middle East into the global chemical industry and increasing competition.

### The global chemical industry is represented by national and multinational associations

The ACC and Cefic are the largest chemical industry associations in the United States and Europe, respectively. However, there are international trade associations that represent each step along the chemical industry value chain (Figure 1.14).

The International Council of Chemical Associations (ICCA) is the trade association of the global chemical industry, including both national and regional associations. It represents chemical companies in 69 countries. ICCA members account for more than 90 per cent of global chemical sales. ICCA works with companies and associations around the world by means of its Responsible Care® Leadership Group, through which global chemical manufacturers commit to an ethic of safe chemical management and chemical management performance excellence (ICCA 2015).

Chemical distributors play an important role in the increasingly globalized chemical industry. They have an essential role to play in chemical supply chains by providing access to hard-to-

**Figure 1.14** International trade associations along the chemical industry value chain (adapted from International Chemical Trade Association [ICTA] 2018a)


reach markets, solving logistical challenges and providing handling services (e.g. repackaging or formulating) while ensuring safety, quality and compliance when working with chemicals. The International Chemical Trade Association (ICTA) represents the interests of over 1,500 chemical distributors worldwide. It promotes the voluntary practices of Responsible Care® and Responsible Distribution, particularly among small and medium-sized enterprises (SMEs) (ICTA 2018b).

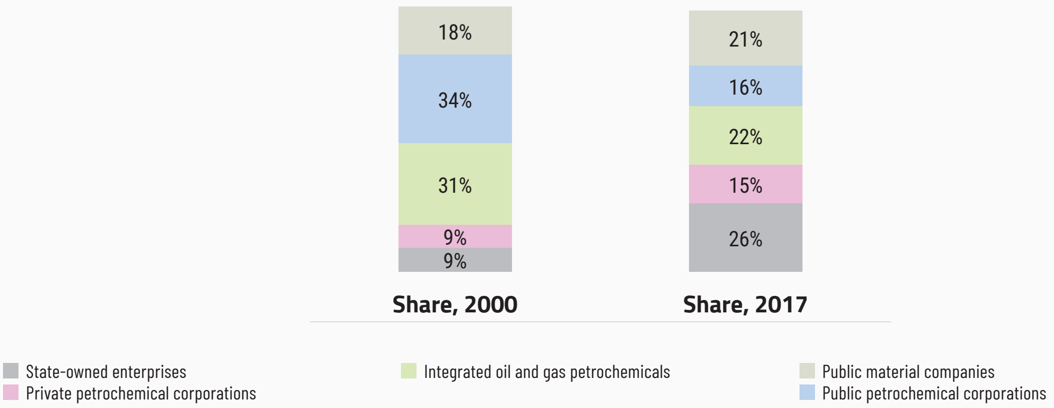
## The proportion of state-owned enterprises in the chemical industry is rising

The chemical industry ownership structure is undergoing significant shifts. State-owned enterprises accounted for only 9 per cent of global chemical industry revenues in 2000, compared with 26 per cent in 2017 (Cayuela and Hagan 2019). Public petrochemical corporations (those whose shares are traded) have lost some of their market share (Figure 1.15). Following a period of lower profitability for pure chemical producers, integrated oil and gas petrochemical companies are moving back into chemicals and

**Box 1.1** Women in leadership positions in the chemical industry

In 2017 *Chemical and Engineering* News undertook a survey to explore gender diversity in chemical companies. While it was noted that the situation is “far from [...] equal representation of women and men in leadership roles”, the survey found significant progress in recent years. In particular, the share of women in board of director positions reached a record high at some 19 per cent. Among executive officers, women accounted for 17 per cent, significantly up from around 10 per cent in the years 2010-2012. 2017 was also a record year for women in leadership positions at chemical companies (Tullo 2017b).

**Figure 1.15** **World chemical industry structure evolution, share of revenue, 2000-2017 (adapted from Cayuela and Hagan 2019)**




materials, spurred by lower oil and gas prices, reduced refining margins and a positive growth outlook for chemical demand. New direct crude-oil-to-chemical-product processes have begun to be pursued, challenging the traditional upstream-refining-petrochemical-materials model (Cayuela and Hagan 2019).

## A period of corporate restructuring, mergers and acquisitions

Current market instability, increasing competition and greater manufactured product recycling (which reduces demand for virgin materials) are reducing the growth rates of many multinational chemical producers. The industry has responded with a period of restructuring and consolidation during the past decade. To achieve greater focus, companies have sought mergers and acquisitions (M&A) to realize higher efficiencies through vertical integration (e.g. through the production of a basic chemical as well as downstream chemicals) and tighter internal integration. Their aggregate value has reached unprecedented levels, with a handful of very large deals (e.g. Linde-Praxair, Dow-DuPont, Monsanto-Bayer and Syngenta-ChemChina) taking the value of M&A in 2016 to the record level of US dollars 260 billion (Sarathy *et al.* 2017; Deloitte 2018; Gryzwa *et al.* 2018) (Figure 1.16). However, following a string of highly publicized megadeals the number of mergers and acquisitions appears to be returning to historic levels (Deloitte 2018).

Significant M&A activity can be observed in the commodities, fertilizers and pesticides

**Figure 1.16** **Number and value of corporate acquisitions in the chemical industry, 2008-2017 (US dollars billion) (Gryzwa *et al.* 2018)**

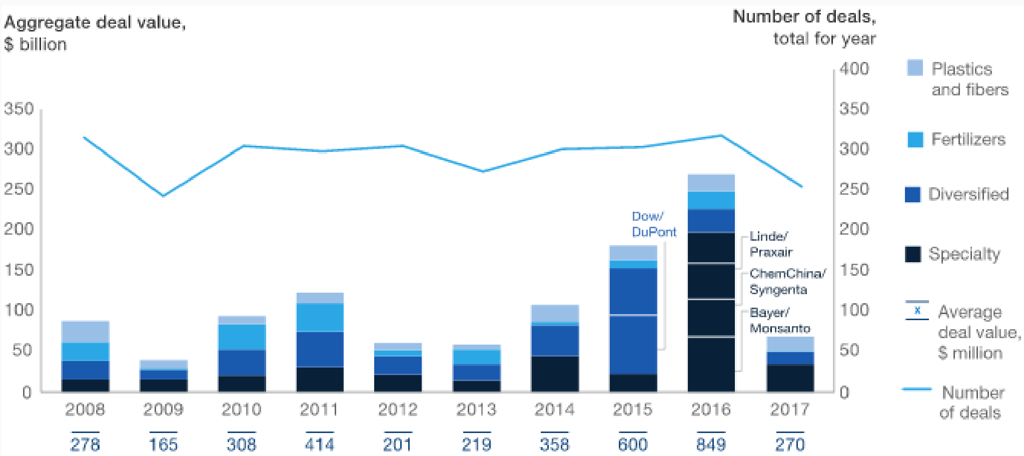
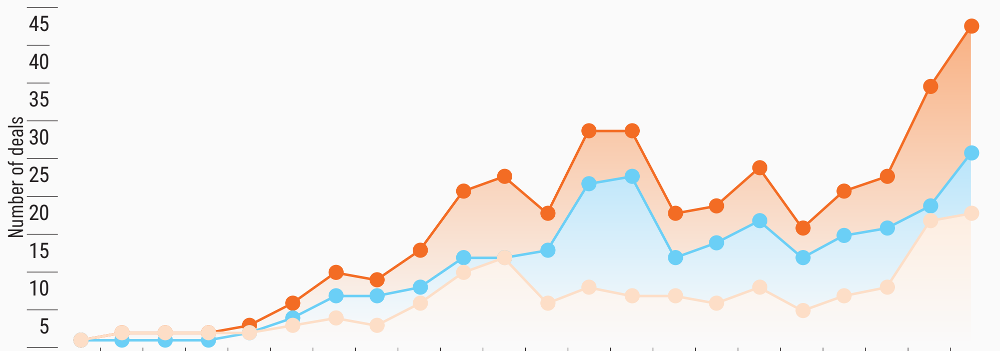


**Figure 1.17** Number of completed mergers and acquisitions in the pharmaceutical industry, 1995-2016 (adapted from Gagnon and Volesky 2017, p. 4)




| | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Global | 0 | 1 | 1 | 1 | 2 | 5 | 9 | 8 | 12 | 20 | 22 | 17 | 28 | 28 | 17 | 18 | 23 | 15 | 20 | 22 | 34 | 42 |
| US | 0 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 5 | 9 | 11 | 5 | 7 | 6 | 6 | 5 | 7 | 4 | 6 | 7 | 16 | 17 |
| Excluding US | 0 | 0 | 0 | 0 | 1 | 3 | 6 | 6 | 7 | 11 | 11 | 12 | 21 | 22 | 11 | 13 | 16 | 11 | 14 | 15 | 18 | 25 |

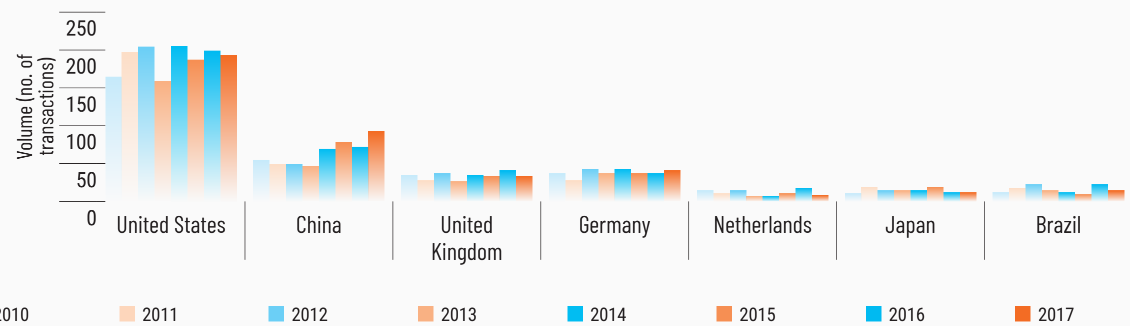
markets (Deloitte 2018). However, mergers and acquisitions have increased most rapidly in the pharmaceutical industry, especially in the United States. Globally, in 1995 there were no deals, in 2014 there were 22 worth US dollars 1.86 billion, in 2015 there were 34 totalling US dollars 33.56 billion, and in 2016 there were 42 worth more than US dollars 44 billion (Gagnon and Volesky 2017) (Figure 1.17).

### A small number of countries account for most mergers and acquisitions

Between 2010 and 2017 the United States was by far the largest target market in terms of volume of transactions, followed by China, which experienced significant growth in the number of mergers and acquisitions between 2013 and 2017 (Figure 1.18). State-owned enterprises in emerging markets have played a strong role in M&A in recent years, with significant implications for the industry given their emphasis on low-cost production (Deloitte 2018).

Cost considerations also offer a strong motivation for SMEs to merge with competitors. In China this trend can be observed as a consequence of higher costs associated with increasing regulatory requirements. At the same time, mergers and acquisitions by Chinese companies have decreased in recent years because of capital outflow restrictions. Drivers may be different

**Figure 1.18** Global chemical mergers and acquisitions activity by target market, 2010-2017 (adapted from Deloitte 2018, p. 11)



**Box 1.2** **The benefits of thorough due diligence during mergers and acquisitions**

Companies engage in mergers and acquisitions because they offer significant benefits such as improving the company's portfolio, increasing production scale and lowering costs. However, a number of risks may manifest themselves and the company's competitiveness may be damaged, with problems ranging from lower than expected economic performance to the costs of litigation and lawsuits. Various risks are of particular concern in the chemical industry due to potential product liabilities (Deloitte 2016). Companies undertaking mergers and acquisitions in the chemical value chain therefore stand to benefit from thorough due diligence that takes into account environmental and human health factors. A comprehensive due diligence helps to identify potential risks and to internalize potential costs associated with liabilities in the price of the acquisition.

Recent cases illustrate the risk of potential financial liabilities associated with mergers and acquisitions. For example, multinational companies recently experienced heavy losses in stock values in the range of billions of US dollars, or had to pay significant compensation, following allegations of lack of diligence or unsound management practices (Bellon 2018; LaVito 2018). In another case, more than 10 years after the acquisition of a humidifier manufacturer in the Republic of Korea by a British company, authorities fined the company for having sold humidifier sterilizer products linked to local cases of lung disease including some 100 deaths, although the product was launched years prior to the acquisition. Fines were imposed, a former executive received a prison sentence, a multi-million US dollar fund was established, and the company publicly apologized (Niemiec 2016; British Broadcasting Corporation 2017).

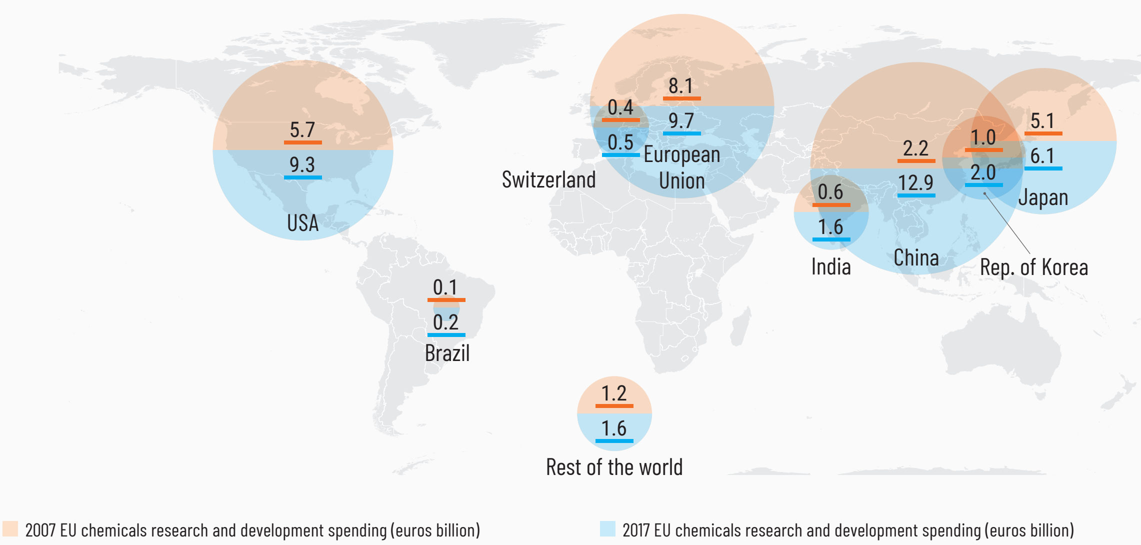
in other countries. For example, portfolio optimization (e.g. a focus on specialty chemicals) has been a key factor in M&A of German companies (Deloitte 2018). As companies acquire assets, particularly when these assets are located in other countries with different regulations, due diligence plays an important role in maximizing opportunities and minimizing the risks of liabilities (Box 1.2).

## 1.5 Research and development trends in the chemical industry

### The industry is investing in R&D, especially in China

The chemical industry continues to invest in potentially high-value areas of research and development (R&D), including nanotechnology,

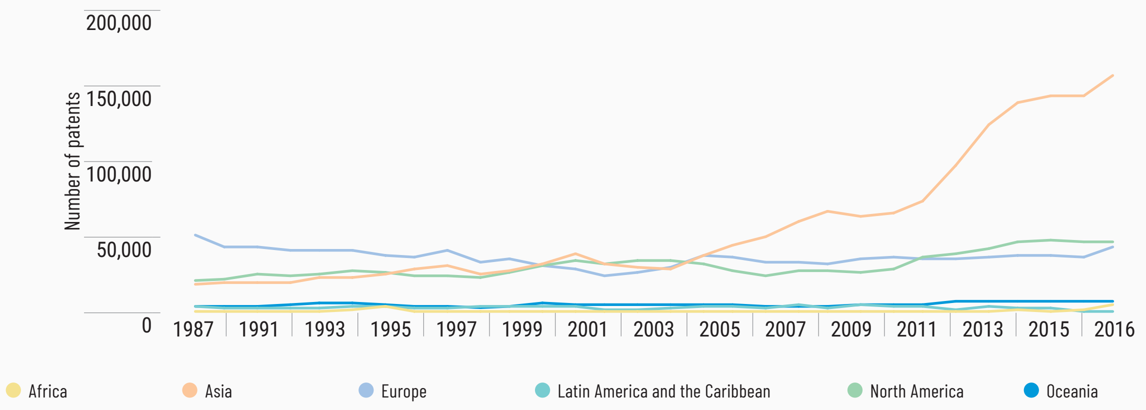
**Figure 1.19** **Corporate research and development spending globally, 2007 and 2017 (EUR billion) (adapted from Cefic 2018, p. 66)**



high-density resins, conductive polymers, organometallics, hydrogels, conversion technologies and biochemistry. In 2017 the global industry spent euros 39.4 billion on R&D. R&D spending by China's chemical industry has exceeded that of all other countries. Between 2007 and 2017 the European industry's spending on R&D grew by 4.6 per cent (Figure 1.19) and that by the industry in the United States by 2.6 per cent, while the Chinese industry's R&D spending grew by 18.8 per cent. During this period R&D spending by the Indian chemical industry grew by 7.8 per cent and that by the industry in Brazil by 4 per cent (Cefic 2018).

The significant growth of spending on R&D in Asia is consistent with the number of patents filed. Data available from the World Intellectual Property Organization (WIPO) show a rapid increase in the number of chemistry-related patents in Asia between 2003 and 2016 compared with other regions (WIPO 2018) (Figure 1.20).

**Figure 1.20** **Number of chemistry-related patents granted by region, 1987-2016 (based on WIPO 2018)**




# 2/ Trends in production and sales of specific chemicals

## Chapter Highlights

The chemical industry spans several market segments, of which basic organic and inorganic chemicals represent the largest share by volume and continue to grow.

Production of some phased-out legacy chemicals of concern has declined significantly.

Production of fertilizers and pesticides, pharmaceuticals, perfluorinated chemicals, flame retardants, nanomaterials, and other groups of chemicals is increasing in many regions.

The market for most heavy metals (including lead and mercury) is stable or increasing, despite regulatory action taken in many countries and at the international level.

Production of plastics, including primary microplastics, is increasing rapidly.

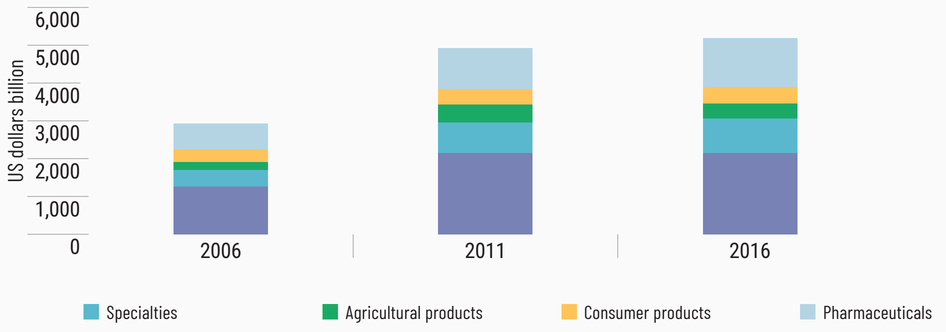
The previous chapter presented an overview of the chemical industry. This chapter focuses on trends in production and sales of specific chemicals or groups of chemicals, many of which are of concern because of their impacts on human health and the environment. Groups of chemicals can be classified in a number of ways. This chapter is structured around basic chemicals, agricultural chemicals, pharmaceuticals, specialty chemicals, metals, manufactured fibres, and plastics. Since the first *Global Chemicals Outlook* was published in 2013 the scale of production of some chemicals has remained steady while that of others has changed appreciably, along with the rates of growth and regional profiles of their markets.

## 2.1 Market segments in the chemical industry value chain

### The chemical industry spans several market segments

The chemical industry can be divided into five market segments: basic chemicals, specialty chemicals, agricultural chemicals, pharmaceuticals, and consumer products. Basic organic and inorganic chemicals (also called "commodity chemicals") are produced in large quantities. They are the foundation feedstock for a wide range of downstream chemicals. Basic organic chemicals include methanol; olefins such as ethylene and propylene; and aromatics such as xylenes, benzene and toluene. Inorganic chemicals include acids and bases; salts; industrial gases; and elements such as the halogens. These chemicals are the feedstocks and intermediaries used to make thousands of specialty chemicals such as solvents; coatings; surfactants and electronic chemicals; agricultural

**Figure 2.1** Global chemical shipments by segment in 2006, 2011 and 2016 (US dollars billion) (adapted from ACC 2017a, p. 31)




chemicals, including pesticides and fertilizers; and the wide array of consumer products sold around the world.

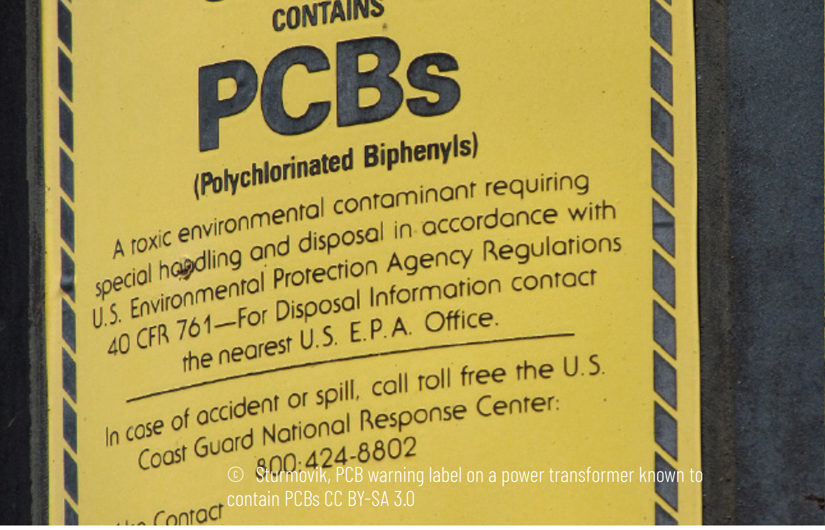
## Recent growth varies by market segment

The ACC provides information on trends in the value of global chemical shipments by market segment. In both 2016 and 2017 pharmaceuticals accounted for 25 per cent of the value of global chemical shipments, while basic petrochemicals and intermediates accounted for about 17 per cent (Table 2.1). Plastic resins made up roughly 13 per cent, and agricultural and consumer products about 8 per cent. The smallest categories were adhesives and sealants and manufactured rubber (1 per cent each) (ACC 2018).

There was a rapid increase in global chemical shipments between 2006 and 2011, followed by slower growth between 2011 and 2016

**Table 2.1** Total global chemical shipments, 2016 and 2017 (US dollars billion) (ACC 2018)

| | 2016 | 2017 |
|---|---|---|
| **Total chemicals** | 5,198 | 5,681 |
| Pharmaceuticals | 1,304 | 1,431 |
| Chemicals, excluding pharmaceuticals | 3,893 | 4,250 |
| Basic chemicals | 2,150 | 2,394 |
| Agricultural chemicals | 421 | 425 |
| Specialty chemicals | 897 | 967 |
| Consumer products | 425 | 465 |
| **Basic chemicals** | | |
| Inorganic chemicals | 386 | 422 |
| Bulk petrochemicals & intermediates | 846 | 943 |
| Plastic resins | 651 | 744 |
| Synthetic rubber | 50 | 52 |
| Manufactured fibres | 216 | 232 |
| **Specialty chemicals** | | |
| Adhesives and sealants | 69 | 76 |
| Coatings | 197 | 214 |
| Other specialties | 631 | 677 |



© Sturmovik, PCB warning label on a power transformer known to contain PCBs CC BY-SA 3.0


© Cjp24, Power transformer originally filled with PCB decontaminated and refilled with mineral oil CC BY-SA 4.0

(Figure 2.1). In the decade 2006-2011 shipments of basic chemicals and pharmaceuticals increased more rapidly than those of chemicals in other segments.

### Production of legacy chemicals – the examples of PCBs and DDT

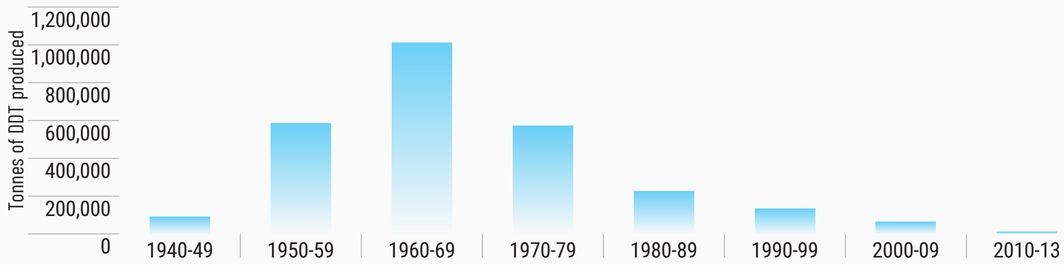
Due, among other reasons, to international action taken, the production and use of some hazardous chemicals has been successfully reduced or phased out. However, ensuring environmentally sound waste management of these chemicals still poses significant challenges. Polychlorinated biphenyls (PCBs), production of which is prohibited for Parties to the Stockholm Convention, are classified by the International Agency for Research on Cancer as Class 1 carcinogenic to humans. A total of around 1 to 1.5 million tonnes of technical grade PCBs have been produced (Table 2.2). Production stated in 1929/1930 and was progressively phased out during the second half of the century. However, one country US dollars was reported to still be producing PCBs as of 2016 (United Nations Environment Programme [UNEP] 2015; UNEP 2016a).

In the case of dichlorodiphenyltrichloroethane (DDT), another one of the original 12 persistent organic pollutants (POPs) covered by the Stockholm Convention, production and use

**Table 2.2 Overview of estimated total production of PCBs (UNEP 2016a, p. 11)**

| Country | Start of production | End of production | Quantity (1,000 tonnes) | |
|---|---|---|---|---|
| | Earliest estimate | Latest estimate | Lowest estimate | Highest estimate |
| Korea (DPR) | 1960s | >2006 | 25 | 30 |
| Soviet Union/Russia | 1938 | 1993 | 180 | 180 |
| Spain | 1930 | 1986 | 25 | 29 |
| Czechoslovakia | 1959 | 1984 | 21 | 21 |
| West Germany | 1930 | 1983 | 59 | 300 |
| Italy | 1958 | 1983 | 24 | 31 |
| France | 1930 | 1984 | 102 | 135 |
| Poland | 1966 | 1977 | 2 | 2 |
| United States | 1929 | 1977 | 476 | 648 |
| China | 1960 | 1983 | 7 | 10 |
| Japan | 1952 | 1972 | 59 | 59 |
| UK | 1951 | 1977 | 66 | 67 |
| **Total** | | | **1,046** | **1,512** |

**Figure 2.2** **Production of DDT by decade since 1940 (adapted from UNEP 2015, p. 44)**




has been significantly reduced. DDT production increased rapidly from the 1940s and reached its peak in the 1960s, with total production exceeding 1 million tonnes annually (Figure 2.2). Thereafter, production quickly and steadily decreased. During the first decade of the new millennium only three countries continued producing DDT. As of 2017, India was the only known remaining producer (UNEP 2015; UNEP 2016a). Both these examples demonstrate the important role of multilateral treaties in stimulating reductions in the production and use of chemicals of concern as well as promoting research and development of alternatives (see also Part II, Ch. 3 and Part III, Ch. 5).

## 2.2 Basic chemicals

### The basic chemicals market continues to expand

Basic organic and inorganic chemicals represent the largest share of global chemical production and consumption by volume (roughly two-thirds of the industry total). The manufacture of basic chemicals is characterized by high capital costs, large-scale production and high energy consumption. Production of basic chemicals is considered a mature industry: the fundamental products, processes and production technologies have changed little during the past 50 years.

The global inorganic chemicals market is highly concentrated. There are a few very large multi-product producers. Nitrogen compounds make up the largest share of the market. However, soda ash and caustic soda sales are growing rapidly as demand for glass and paper products increases. Rising demand for food and cosmetic products is also driving the inorganic chemicals market. The global inorganic chemicals market totalled US dollars 277 billion in 2017. It is estimated that this market will reach US dollars 362 billion by 2022, increasing at a CAGR of 5.5 per cent (BCC Research 2018).

The global organic chemicals market is largely composed of petrochemicals (chemicals derived from fossil fuels). More than 90 per cent of all organic chemistry products are derived from seven petrochemicals: benzene, toluene and xylene (aromatics); ethylene, propylene and butadiene (olefins); and methanol. (ACC 2017b). Globally, shipments of petrochemicals and their derivatives (e.g. organic intermediates, plastic resins and synthetic fibres) account for the largest share of shipments of basic chemicals. The highest global production capacity for petrochemicals includes ethylene, propylene

**Table 2.3** **Global production capacity for petrochemicals, 2016 (Smith, Glauser and Eramo 2017)**

| Chemical | Percentage of global market |
|---|---|
| Ethylene | 27.9% |
| Propylene | 20.3% |
| Methanol | 19.6% |
| Xylenes | 12.6% |
| Benzene | 10.6% |
| Toluene | 6.6% |
| Butadiene | 2.5% |

**Table 2.4** Evolution of global production capacity for primary petrochemical building blocks (kg per capita) (Cayuela and Hagan 2019)

| | World population (billion) | High-value chemicals | | | | | | Average high-value chemicals |
|---|---|---|---|---|---|---|---|---|
| | | Olefins | | | Aromatics | | | |
| | | Ethylene | Propylene | Butadiene | Benzene | Toukene | Xylenes | |
| 1990 | 5.3 | 11.9 | 7.1 | 1.5 | 5.8 | 3.1 | 4.1 | 33.5 |
| 2000 | 6.1 | 16.0 | 10.8 | 1.5 | 7.1 | 3.7 | 6.2 | 45.4 |
| 2010 | 6.9 | 21.1 | 15.0 | 1.8 | 8.3 | 4.9 | 8.7 | 59.9 |
| 2017 | 7.4 | 23.0 | 18.2 | 2.0 | 8.5 | 5.4 | 10.2 | 67.3 |
| Estimated growth by 2030 (business as usual scenario) | 8.5 | 26.2 | 19.4 | 2.2 | 8.7 | 7.1 | 16.4 | 79.9 |
| CAGR | 1.2% | 2.0% | 2.5% | 1.0% | 1.0% | 2.1% | 3.5% | 2.2% |

and methanol, followed by xylenes, benzene and toluene (Smith, Glauser and Eramo 2017) (Table 2.3).

The petrochemical industry has been robust since the start of the century, buoyed by high demand in the emerging economies and low-cost gas feedstocks. The global market for petrochemicals is expected to grow at a CAGR of around 8.8 per cent to reach US dollars 975 billion by 2025. Factors influencing this growth include increasing demand for propylene products, favourable regulatory policies in emerging economies, and increasing use of coal and shale gas as major feedstocks for petrochemicals production (Cision 2017). The global production capacity for primary petrochemical building blocks has been growing faster than the world population (Table 2.4), pointing to increased future per capita chemicals consumption. For example, the production capacity for xylenes, which was 4.1 kg per capita in 1990, is projected to reach 16.4 kg per capita by 2030 (Cayuela and Hagan 2019).

## 2.3 Agricultural chemicals

### Markets are growing to keep pace with demand for food and fibre

The global market for agricultural chemicals is driven by continuing world population growth and rising living standards, which require an increasing and diverse food supply. The global market for agricultural chemicals was US dollars 215.18 billion in 2016 and is projected to reach US dollars 308.92 billion by 2025 (ACC 2017b).

### 2.3.1 Fertilizers

#### The market for agricultural chemicals is dominated by fertilizers

Fertilizers make up the largest share of agricultural chemicals by volume. The Food and Agriculture Organization of the United Nations (FAO) has estimated that global consumption of the three fertilizer nutrients nitrogen (N), phosphorous (expressed as phosphate ($P_2O_5$)) and potassium (expressed as potash ($K_2O$)) reached 186.67 million tonnes in 2016, an increase of 1.6 per cent compared with 2015. The FAO further forecast that demand for N, $P_2O_5$ and $K_2O$ will grow by 1.5, 2.2 and 2.4 per cent annually until 2020. Global capacity for producing fertilizers, intermediates and raw materials was also expected to increase during this period (FAO 2017). The International Fertilizer Association (IFA) has estimated that between 2018 and 2022 the industry will invest close to US dollars 98 billion in more than 60 new fertilizer production units, adding 78 million tonnes of production capacity (IFA 2018). The largest share of fertilizer consumption occurs in Asia, where the fertilizer market has been growing most rapidly (Mateo-Sagasta, Zadeh and Turral 2017).

### 2.3.2 Pesticides

#### Continued growth in the pesticide/crop protection industry

Pesticides include herbicides, insecticides, termiticides, nematicides, rodenticides and fungicides. These products are largely used for crop protection in agriculture. While biocides (including bactericides, preservatives and disinfectants) are included in this economic segment, they are largely used in manufacturing, medical facilities, commercial facilities, schools and residences. In 1960 the global crop protection industry was worth less than US dollars 10 billion and around 100 active ingredients were available to farmers. Today the industry is valued at over US dollars 50 billion and there are around 600 active ingredients. Herbicides account for approximately 80 per cent of all pesticide use (Phillips McDougal 2018).

Asia has been the largest producer of pesticides in the past decade, with the largest manufacturing capacity in China. Pesticide production in Europe and the United States has remained fairly stable, while growth in Latin America has been increasing steadily (Table 2.5).

While pesticide production has grown steadily in volume, the value of global trade has grown even more rapidly, particularly since 2002 (Mateo-Sagasta, Zadeh and Turral 2017) (Figure 2.3)

Over the past decades the insecticide market has shifted away from organochlorinated compounds to organophosphorus compounds and biopesticides (including microbials [bacteria, algae, protozoa viruses and fungi], pheromones and semiochemicals, macrobials/invertebrates such as insects and nematodes, and plant extracts/botanicals). Table 2.6 shows the transition in pesticide sales in the United States between 1968 and 2016, noting changes due to government and international agreement regulations, product innovation and market pressures (Phillips McDougal 2018).

Around 300 biopesticide active substances and organisms are currently available, including products derived from fermentation, microbes and pheromones, and predatory insects (Phillips McDougal 2018). As the growth of low-pesticide organic and sustainable or agroecological agriculture increases globally, the market for conventional pesticides used in agriculture is expected to decline. Although the rate of new product approvals has fallen in recent years, investment remains high, with major companies investing 7-10 per cent of their sales annually (Phillips McDougal 2018). Major constraints on the development of new pesticides include high R&D costs and the extensive testing necessary to apply for government registrations (Elsevier 2017; European Federation of Pharmaceutical Industries and Associations [EFPIA] 2018; Phillips McDougal 2018; Transparency Market Research n.d.).

**Table 2.5 Global manufacture of pesticide active ingredients by region, 2008-2016 (thousand kg) (Oliver 2018)**

| | 2008 | 2010 | 2012 | 2014 | 2016 |
|---|---|---|---|---|---|
| Asia | 822,485 | 1,066,678 | 1,236,767 | 1,204,490 | 1,265,285 |
| China | 417,477 | 454,239 | 678,545 | 760,416 | 887,564 |
| India | 104,557 | 124,018 | 133,754 | 161,912 | 195,983 |
| Latin America | 410,366 | 419,694 | 475,955 | 549,150 | 645,412 |
| North American Free Trade Agreement | 410,751 | 502,257 | 523,957 | 576,254 | 547,625 |
| United States | 406,102 | 477,830 | 492,070 | 498,155 | 498,149 |
| Europe | 382,352 | 434,846 | 464,858 | 513,745 | 515,490 |
| **Total global** | **1,979,402** | **2,342,879** | **2,577,086** | **2,665,617** | **2,837,770** |

**Figure 2.3** Value of global pesticide trade, 1970-2016 (US dollars billion) (adapted and updated based on Mateo-Sagasta, Zadeh and Turral 2017, p. 10)

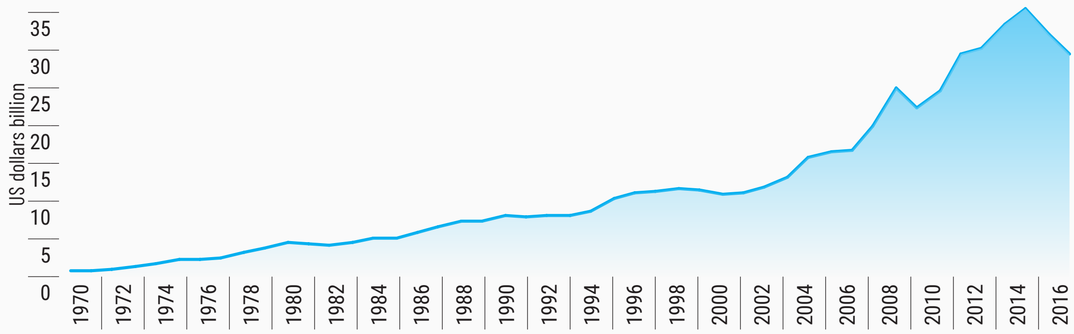
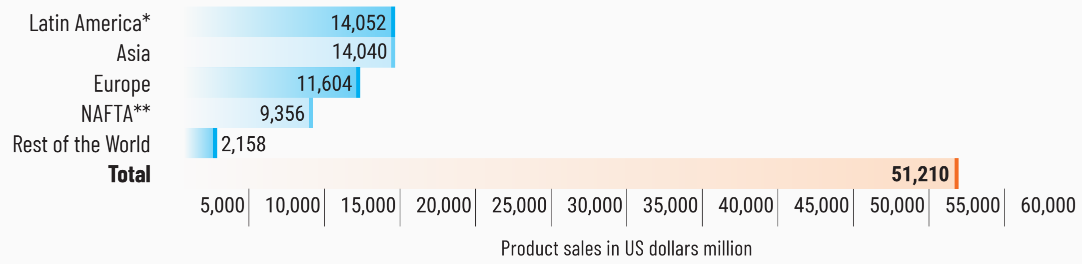



**Table 2.6** Top 10 products used on major crops in the United States by volume, 1968 and 2016 (Phillips McDougal 2018, p. 4)

| Top 10 products in 1968 | Top 10 products in 2016 |
|---|---|
| Atrazine | Glyphosate |
| Toxaphene - *banned* | Metolachlor |
| DDT - *banned** | Pyraclostrobin |
| 2,4-D | Mesotrione |
| Methyl parathion - *banned* | Thiamethoxam |
| Aldrin - *banned* | Acetochlor |
| Trifluralin | Azoxystrobin |
| Propachlor | Atrazine |
| Dinoseb - *banned* | Abamectin |
| Chloramben - *banned* | Clothianidin |

*DDT is banned globally as an agricultural and household pesticide, but is allowed for vector control in some countries when locally safe, effective and affordable alternatives are not available.

**Figure 2.4** **Global and regional sales of crop protection products in 2015 (US dollars million) (based on Informa 2017, p. 40)**




* Excluding Mexico

** NAFTA - North American Free Trade Agreement

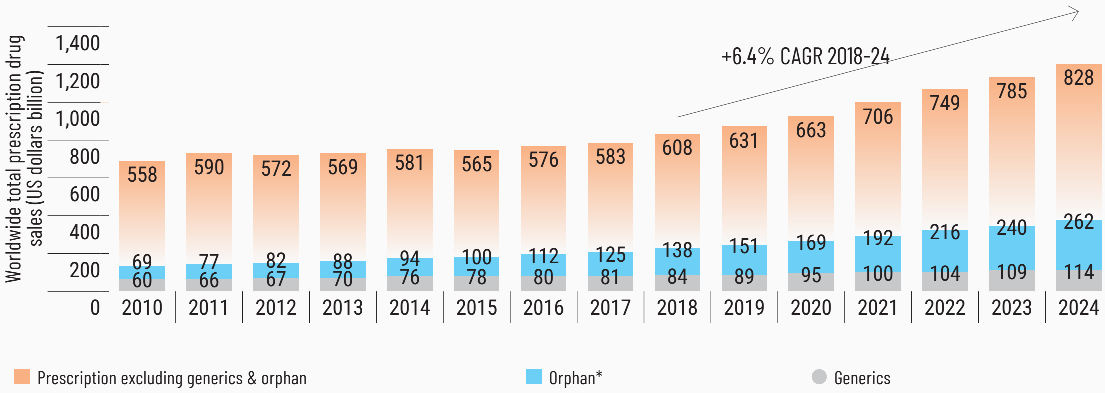
Historically the largest pesticide markets have been in North America and Europe; however, markets for crop protection products are currently growing faster in Asia and South America than in those regions (Informa 2017) (Figure 2.4). Between 2013 and 2014 the value of markets in South America increased by 13 per cent, while the value of those in Africa and the Middle East, Europe and the Asia-Pacific grew at lower rates and the value of markets in North America (Canada, the United States and Mexico) fell by more than 4 per cent. Important regional factors influencing these trends include a strong agricultural sector in South America, increasing food demand worldwide, and declining crop prices in Europe, North America and Asia (CropLife International 2015).

## 2.4 Pharmaceuticals

### The production and sales of pharmaceuticals are growing rapidly

The global pharmaceutical market will reach nearly US dollars 1,485 billion by 2021, up from US dollars 1,105 billion in 2016 (International Federation of Pharmaceutical Manufacturers and Associations [IFPMA] 2017), equivalent to an annual growth rate exceeding 6 per cent. Global prescription drug sales are projected to grow quickly, at 6.4 per cent CAGR in 2010-2024 (Figure 2.5). Assuming a similar growth rate thereafter would see global sales almost double by 2030.

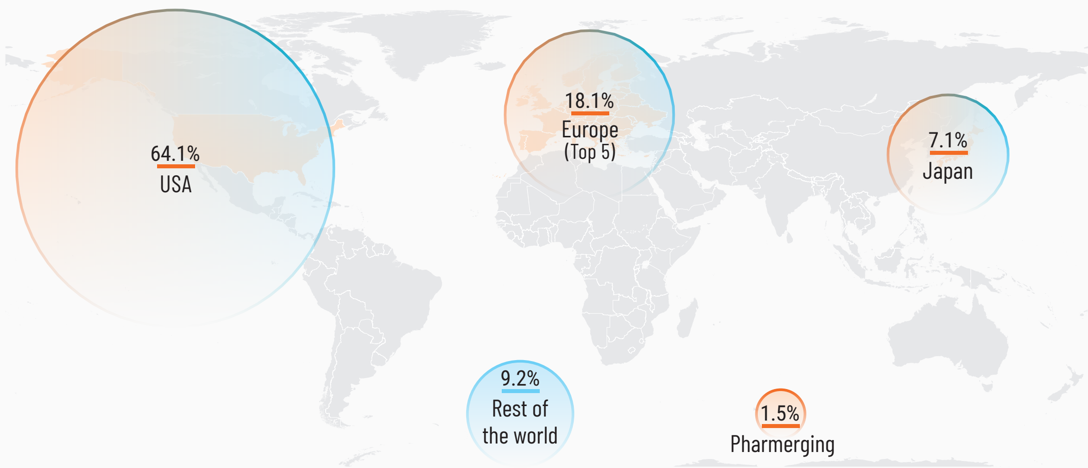
**Figure 2.5** Worldwide total prescription drug sales (US dollars billion) and growth rate (per cent), 2010-2024 (adapted from EvaluatePharma 2018, p. 8)




* An orphan drug is a pharmaceutical agent developed to treat medical conditions which, because they are so rare, would not be profitable to produce without government assistance.

Emerging markets in Asia, Latin America, Russia, the Middle East and Africa are expected to stimulate new growth during the next decade owing to increasing demand (Gautam and Pan 2016). The term 'Pharmerging' markets has been introduced to refer to 21 countries ranked by IQVIA (formerly Quintiles and IMS Health, Inc.) as high-growth pharmaceutical markets, namely Algeria, Argentina, Bangladesh, Brazil, Colombia, Chile, China, Egypt, India, Indonesia, Kazakhstan, Mexico, Nigeria, Pakistan, the Philippines, Poland, Russia, Saudi Arabia, South Africa, Turkey and Viet Nam (EFPIA 2018). Another factor driving the growth in pharmaceuticals production and sales is increasing demand from an ageing population in developed countries (IFPMA 2017). Despite

**Figure 2.6** Geographical breakdown (by main markets) of sales of new medicines launched in the period 2012-2017 (adapted from EFPIA 2018, p. 4)




The figure shows the share of sales of new medicines covering all new active ingredients marketed for the first time on the world market during the period 2012-2017, with Europe (Top 5) comprising Germany, France, Italy, Spain and the United Kingdom. While this figure suggests that innovation markets are still concentrated in the US and Europe, pharmaceutical markets in emerging economies, including the pharmerging countries, are projected to experience significant growth.

significant growth in the emerging economies, the pharmaceutical sector is still dominated by markets in North America and Europe, particularly in sales of medicines marketed for the first time on the world market in recent years (Figure 2.6). Most consumption occurs in the higher-income countries where most of the top 10 drug companies are located, although drug manufacture often occurs in emerging economies. The United States dominates the global market, in terms of both consumption and development, and is projected to hold around 41 per cent of the global market share in 2020 (IFPMA 2017). Between 2010 and 2016 total expenditure on pharmaceuticals in that country grew from approximately US dollars 316 billion to US dollars 450 billion. This represents about 64.7 per cent of global sales of new medications launched between 2010 and 2015 (McGovern 2018).

The pharmaceutical industry is highly innovative and competitive. It is heavily dependent on research and is subject to strong government regulation in higher-income countries. The industry has been shifting away from the development of primary care and small-molecule medicines, while progressively transitioning towards specialty medications and biologics targeted at high unmet patient needs (United States Food and Drug Administration 2018).

## 2.5 Specialty chemicals

### 2.5.1 Per- and polyfluorinated chemicals

#### The variety of per- and polyfluorinated chemicals is large and increasing

Per- and polyfluoroalkyl substances (PFASs) are used in firefighting foams and as coatings for textiles, paper, non-stick cookware and other products. Long-chain compounds (eight carbons), such as perfluorooctane sulphonate (PFOS) and perfluorooctanoic acid (PFOA), are used as inputs in the production of a range of fluoropolymers (OECD 2013). The OECD has identified some 4,700 PFASs-related compounds (OECD 2018a.). World consumption of all fluoropolymers in 2015 was 297,000 tonnes, with polytetrafluoroethylene (PTFE) accounting for more than half of all consumption. China was both the largest producer and largest consumer of PTFE in 2015 (Zhang *et al.* 2016) (Table 2.7). Overall, production of fluoropolymers is shifting from the United States, Europe and Japan to China, as it is an important producer of fluorspar, from which fluorine is derived (Zhang *et al.* 2016) (Table 2.7).

**Table 2.7 Geographic distribution of fluoropolymer consumption in 2015 in tonnes (per cent share) (Zhang *et al.* 2016)**

| | PTFE | All fluoropolymers |
|---|---|---|
| United States | 15 | 22 |
| Western Europe | 18 | 16 |
| Japan | 5 | 5 |
| China | 44 | 38 |
| Rest of the world | 17 | 19 |

Production and use of PFOS and PFOA have been restricted in the EU (Janshekar *et al.* 2015) and in Canada since 2009 and 2016, respectively (Government of Canada 2019a; Government of Canada 2019b), and voluntarily phased out by manufacturers in the United States due to concerns about health and environmental effects. PFOS is currently listed as restricted under the Stockholm Convention, while PFOA has been proposed for listing (Secretariat of the Stockholm Convention 2008). Consequently, these chemicals are being replaced by shorter-chain (e.g. six- or four-carbon) perfluorinated compounds. However, these shorter-chain compounds are also highly persistent in the environment and present some of the same health and environmental concerns as their longer-chain counterparts (Brendel *et al.* 2018).

### 2.5.2 Flame retardants

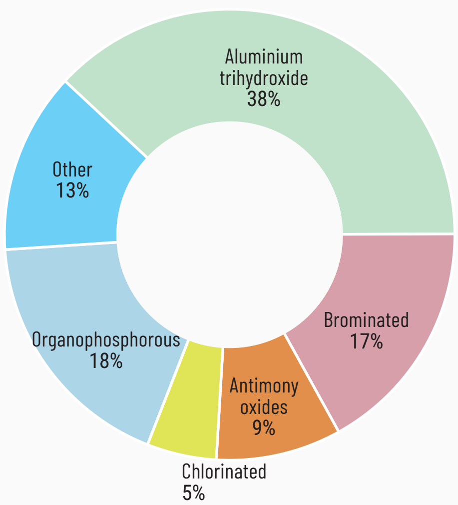
#### Production and use of certain flame retardants is increasing, but shifting due to regulatory action

Flame retardants are used to deter or extinguish flame propagation in many plastics, resins, textiles, elastomers, coatings, adhesives and sealants. There are around 80 types of brominated flame retardants with widely varying chemical properties. There are five brominated flame retardants that, historically, are the most widely used and about which there is considerable knowledge: pentabromodiphenyl ether, octabromodiphenyl ether, decabromodiphenyl ether, tetrabromobisphenol A and hexabromocyclododecane.

In 2017 worldwide consumption of flame retardants amounted to more than 2.25 million tonnes per year. Aluminium hydroxide is the largest selling flame retardant (38 per cent of the market). Halogenated flame retardant systems comprising brominated and chlorinated products, which are commonly used together with the synergist antimony trioxide, make up another 31 per cent. Organophosphorus and other flame retardants (e.g. inorganic phosphorus compounds, nitrogen- and zinc-based flame retardants) make up the remaining 31 per cent (IHS Markit 2017) (Figure 2.7).

Global consumption of flame retardants has been forecast to grow at an average annual rate in the lower 3 per cent range between 2016 and 2021. Government regulations and policies targeting some or (in some cases) all chemical flame retardants have slowed growth of consumption (IHS Markit 2017; United States Environmental Protection Agency [US EPA] 2017a). The use of hexabromocyclododecane (HBCD), once one of the largest-volume products, is restricted under the Stockholm Convention and is no longer allowed in Japan and the EU. Because of such pressures there is an ongoing shift from most brominated compounds to organophosphorus, aluminium trihydroxidephosphorus compounds, or brominated co-polymers of styrene and 1,3 butadiene in insulating foams. China is the largest market for flame retardants; however, since restrictions have been placed on HBCD the market is shifting towards phosphorous compounds (IHS Markit 2017).

**Figure 2.7** **Global flame retardants market by chemistry, 2017 (adapted from IHS Markit 2017)**




## 2.5.3 Nanomaterials

### The nanomaterials market is expanding rapidly

Nanomaterials are materials with at least one dimension measuring between 1 to 100 nanometres. They can be made from various combinations of gold, copper, carbon, silver, iron, platinum and other elements, as well as clays and cellulose (Rothfeder 2017). According to one set of estimates, the global nanotechnology market could grow from US dollars 39.2 billion in 2016 to US dollars 90.5 billion by 2021 (a five-year CAGR of 18.2 per cent). This would include well-established commercial applications such as nanoparticle-based sunscreen products and nano-catalyst thin films for catalytic converters, as well as new technologies such as thin film solar cells, nanolithographic tools and nanoscale electronic memories. Nanoparticles and nanoscale thin films dominate the nanomaterials market (BCC Research 2017).

The largest end-use markets for nanotechnology in 2015 were environmental applications (38.8 per cent of the total market), electronics (22.4 per cent) and consumer applications (21.1 per cent) (BCC Research 2017). Nano silver, due to its antibacterial and antimicrobial properties, is among the most popular nanomaterials used in the manufacture of consumer products, with most uses in electronics, information technology, health care, textiles and personal care products. Titanium dioxide and silicon dioxide nanoparticles are also widely used (Inshakova and Inshakov 2017).

However, a range of scenarios and estimates exist regarding the future of the global nanomaterials market. Factors affecting its development include concerns about impacts on human health and the environment during product production, use and disposal, as well as evolving government regulations (US EPA 2017b; European Chemicals Agency [ECHA] 2018; OECD 2018b).

## 2.6 Metals

### 2.6.1 Lead

#### Global lead production has remained stable

Global lead production and use remained roughly constant between 2013 and 2017, although over half comes from secondary production as recycled lead (International Lead and Zinc Study Group [ILZSG] 2018). Mine production fell somewhat during this period, primarily due to declining mine production in China (Guberman 2017) (Table 2.8).

**Table 2.8** Global refined lead production and usage (thousand tonnes), 2013-2018 (ILZSG 2018)

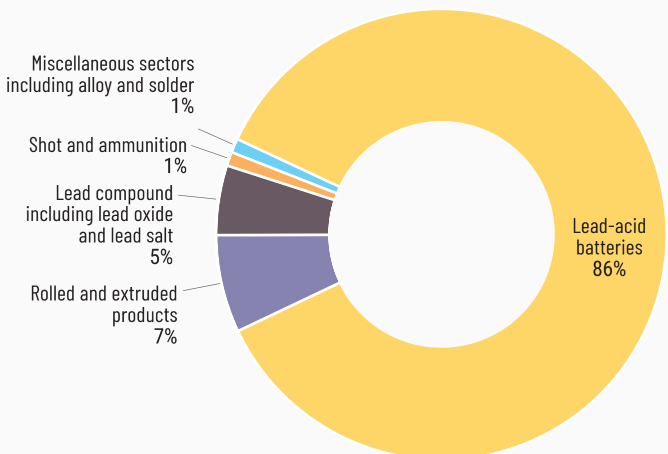
| | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|
| Mine lead production | 5,089 | 4,946 | 4,850 | 4,679 | 4,703 |
| Total lead production | 11,225 | 11,023 | 10,959 | 11,158 | 11,445 |

China is the largest producer of lead from mines, accounting for 52 per cent of global production in 2017. It is also the top producer of refined lead, estimated to have produced about 43 per cent of total global refined lead in 2015; the United States was second, accounting for an estimated 10 per cent (United States Geological Survey [USGS] 2018a). China was also the top lead consumer and the top producer of lead-acid batteries in 2015 (Guberman 2017).

#### The market for lead-acid batteries is projected to grow significantly in some regions

Globally, in 2018 about 86 per cent of lead was used in lead-acid batteries. Most of this lead came from battery recycling (ILZSG 2019) (Figure 2.8). Spent lead-acid batteries from vehicles are one of the world's most recycled consumer products. In the United States and Europe nearly 100 per cent of these batteries are recovered for recycling (International Lead Association 2018). In China the growing production of lead-acid batteries for use in automobiles, electronic bicycles and other applications is the key driver of the global market (Guberman 2017). The market for lead-acid batteries in Africa (where lead-acid battery recycling and the presence of these batteries as

**Figure 2.8** Global lead consumption by product, 2018 (adapted from ILZSG 2019)



hazardous waste present risks to health and the environment) is expected to grow significantly, potentially increasing from around US dollars 709 million in 2014 to more than US dollars 1,000 million in 2021 (Transparency Market Research 2016).

Lead use in other applications is declining following regulatory action taken in many countries. For example, 71 countries have legally binding controls to limit the production, import and sale of lead paints (UNEP 2018). In addition, lead-free options are used increasingly for wire and cable jacketing; tin is replacing lead for solder in drinking water systems; and electronic products are increasingly manufactured without lead.

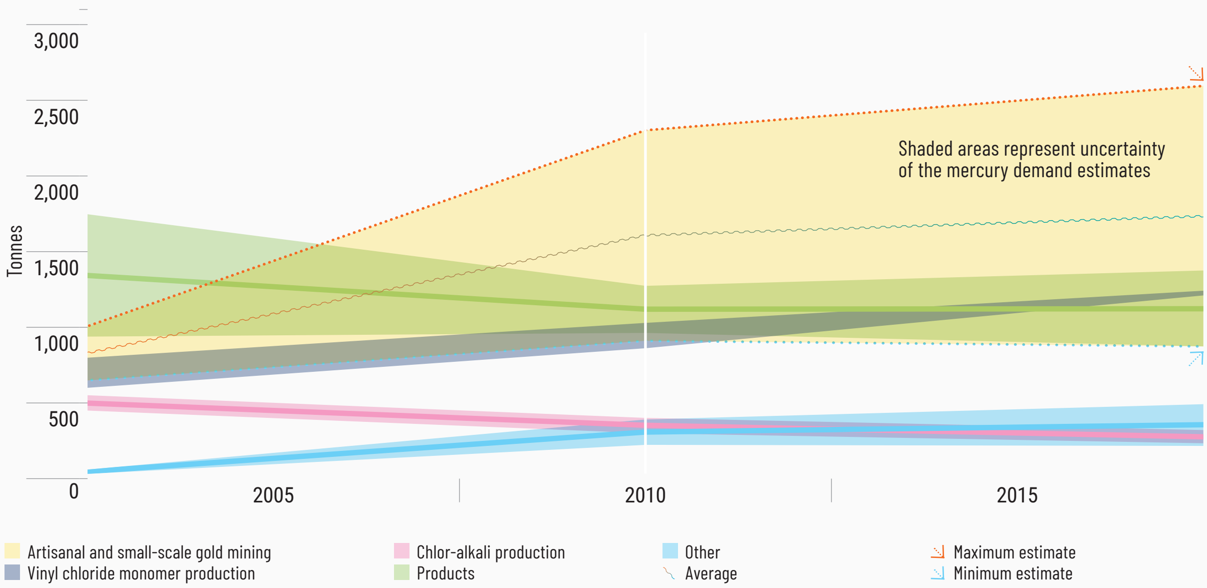
### 2.6.2 Mercury

#### Driven by continued growth in major applications, global mercury mining has increased rapidly

Mercury is used in a variety of applications, including (in order of magnitude as of 2015) artisanal and small-scale gold mining (ASGM), vinyl chloride monomer (VCM) production, measuring and control devices, chlor-alkali production, dental amalgams and batteries. ASGM and VCM production are responsible for over 60 per cent of global mercury demand. Between 2005 and 2015 worldwide mercury use increased overall. While consumption for some applications (including chlor-alkali production, batteries and electrical/electronic devices) has decreased, other applications have increased significantly, particularly VCM production and ASGM (Figure 2.9). By 2015 global mercury demand was in the range of 4,500 to 4,900 tonnes, over half of which in East and Southeast Asia (UNEP 2017).

The global mercury market is highly dynamic. One of the major changes in mercury supply since the 2013 *Global Chemicals Outlook* is the reduced supply of residual mercury from the chlor-alkali industry due to restrictions imposed by export bans. The former EU and United States trading hubs have given way to those in emerging economies. Recent shifts in mercury

**Figure 2.9** Global mercury demand by sector, including uncertainties, 2005-2015 (tonnes) (adapted from UNEP 2017, p. 63)




Products refers to batteries, dental applications, measuring and control devices, lamps, electrical and electronic devices.

Other refers to paints, laboratory, pharmaceutical, cultural/traditional uses, etc.

**Table 2.9** **Global mercury supply, 2015 (tonnes) (UNEP 2017, p. 21)**

| Mercury source | Min. mercury supply (tonnes) | Max. mercury supply (tonnes) |
|---|---|---|
| Primary (mined) mercury | 1,630 | 2,150 |
| By-product mercury | 440 | 775 |
| Chlor-alkali residual mercury | 370 | 450 |
| Mercury recycling | 1,040 | 1,410 |
| **Total supply** | **3,480** | **4,785** |

trade have also been accompanied by an increase in undocumented or illegal trade (UNEP 2017).

In 2015 global supply from various sources totalled between 3,480 and 4,785 tonnes (Table 2.9). As demand for mercury for ASGM and VCM production has increased, this demand has been met through increased primary mercury mining, including opening of new mercury mining sites in Mexico and Indonesia, most of which are informal (UNEP 2017). The only other countries mining mercury are China and the Kyrgyz Republic. China is by far the largest producer of mercury. In 2015 global primary mercury production, both formal and informal, was estimated to be in the range of 1,630-2,150 tonnes (UNEP 2017). In addition, a number of countries produce mercury as a by-product during the mining of non-ferrous ores and the extraction of oil and natural gas. The entry into force of the Minamata Convention on Mercury is expected to affect global mercury production and use significantly (see Part II, Ch. 1-3).

## 2.6.3 Cadmium

### Production of cadmium is stable as demand shifts across applications

The largest use of cadmium is in nickel-cadmium (NiCd) batteries. Other end uses include pigments, polyvinyl chloride (PVC) stabilizers, anti-corrosive coatings, non-ferrous alloys and photovoltaic devices. Global cadmium production has remained approximately constant since 2012, somewhat above 20,000 tonnes per year excluding production in the United States, which is not reported (Table 2.10). However, the geographic distribution of production has changed significantly. Most of the world's primary production (e.g. mining) takes place in the Asia-Pacific region (59 per cent), followed by Europe and Central Eurasia with 22 per cent production, North America with 15 per cent and South America with 4 per cent. Secondary production (e.g. recycling of NiCd batteries) currently takes

© Zoï Environment Network, Primary mercury mine in Khaidarkan, Kyrgyzstan

**Table 2.10 Cadmium: refinery production by country, 2012-2016 (tonnes) (Tolcin 2018, p. 16.8)**

| Country | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Argentina | 37 | 28 | 30[e] | 30[e] | 30[e] |
| Australia | 380 | 380 | 350 | 380 | 400 |
| Brazil | 200 | 200 | 200 | 200 | 200 |
| Bulgaria | 360 | 411 | 382 | 344 | 340[e] |
| Canada | 1,290 | 1,310 | 1,190 | 1,160 | 2,310 |
| China | 7,270 | 7,500 | 8,200 | 8,200[e] | 8,200[e] |
| Germany | 400 | 400 | 400 | 400 | 400 |
| India | 396 | 285 | 107 | 200[e] | 21 |
| Japan | 1,860 | 1,830 | 1,830 | 1,960 | 1,990 |
| Kazakhstan | 1,170 | 1,320 | 1,630 | 1,460 | 1,500[e] |
| Korea, Republic of | 3,900 | 3,900 | 4,090 | 3,600 | 3,600 |
| Mexico | 1,480 | 1,450 | 1,410 | 1,280 | 1,190 |
| Netherlands | 560 | 610 | 640 | 640 | 630 |
| Norway | 310[e] | 310 | 310 | 310 | 310[e] |
| Peru | 684 | 695 | 769 | 757 | 820 |
| Poland | 370 | 460 | 628 | 383 | 400[e] |
| Russia | 1,500[r] | 1,200 | 1,200 | 1,200 | 1,300 |
| United States | W | W | W | W | W |
| Uzbekistan | 300 | 300 | 300 | 300 | 300 |
| Total | **22,500** | **22,600** | **23,700** | **22,800** | **23,900** |

e = estimated, p = preliminary, w = withheld to avoid disclosing proprietary data; not included in total

place in facilities in Asia, Europe and the United States (Tolcin 2018).

In the future it is likely that some factors will reduce cadmium demand while others will increase it. The amount of cadmium used in NiCd batteries is decreasing. However, use of cadmium telluride (CdTe), a principal component of lightweight, low-cost thin-film photovoltaic (PV) solar panels, will likely soar in years to come as more thin-film PV panels are produced globally (Fthenakis n.d.). Regulations, especially in the EU, are reducing or eliminating cadmium use in many applications (USGS 2016). Lithium-ion batteries have significantly replaced NiCd batteries in some low-cost electronic products. This trend is expected to continue as lithium-ion efficiency increases and manufacturing costs fall. Nevertheless, NiCd batteries continue to be used in industrial applications such as electric vehicles and hybrid power systems that generate electricity in remote locations. Regardless of cadmium demand, zinc smelting processes and NiCd battery retirement will continue to produce by-products containing cadmium, which may need to be managed as demand for cadmium continues to decline (Tolcin 2018).

### 2.6.4 Rare earth minerals

#### China dominates the market for rare earth minerals

Seventeen elements found within the Earth's crust are considered rare earth elements. The largest global use of these elements globally is in production of high-performance lightweight neodymium ion boron (NdFeB) and samarium cobalt (SmCo) permanent magnets, which are used in the growing markets for wind turbines and electric vehicles. Other end products include polishing powders, vehicle emissions control catalysts, rechargeable batteries, glass additives and phosphors (Wietlisbach and Gao 2016; Pavel *et al.* 2017).

China has been the dominant supplier and user of rare earths during the last 20 years (Table 2.11). In 2015 it produced 84 per cent and consumed 65 per cent of available global rare earths. China's influence on world production has fallen slightly since 2012 as a result of increased production in Australia and the United States. World consumption of rare earths peaked at 138,000 tonnes in 2007; it was estimated to be 121,000 tonnes in 2015. Global consumption is expected to increase by 2.4 per cent annually through 2020 (Dutta *et al.* 2016; Wietlisbach and Gao 2016).

## 2.7 Asbestos

### Regulatory action has successfully reduced the demand for asbestos, but production continues

Increasing regulation at the national level has slowed the consumption and production of asbestos. In 1980 only three countries had asbestos bans, but the number has grown to 70 today (Kazan-Allen 2018). Estimated worldwide consumption of asbestos minerals fell from approximately 2 million tonnes in 2010 to nearly 1.4 million tonnes in 2016; asbestos cement products are expected to continue to be the leading global market for asbestos (USGS 2018a).

Notwithstanding, production of asbestos continues. As of 2016, the leading producers were Russia China, Kazakhstan and Brazil (Figure 2.10). Brazil accounted for roughly 10 per cent of global production and consumption in 2017; however, in that year the Brazilian Supreme Federal Court enacted a ban on the extraction, commercialization and use of asbestos (Kazan-Allen 2017). Pending further legal action, the only remaining commercial producers will be China, Kazakhstan, Russia and potentially Zimbabwe, where two former asbestos mines could possibly reopen (Guberman 2017).

## 2.8 Plastics

### Plastics production is growing exponentially

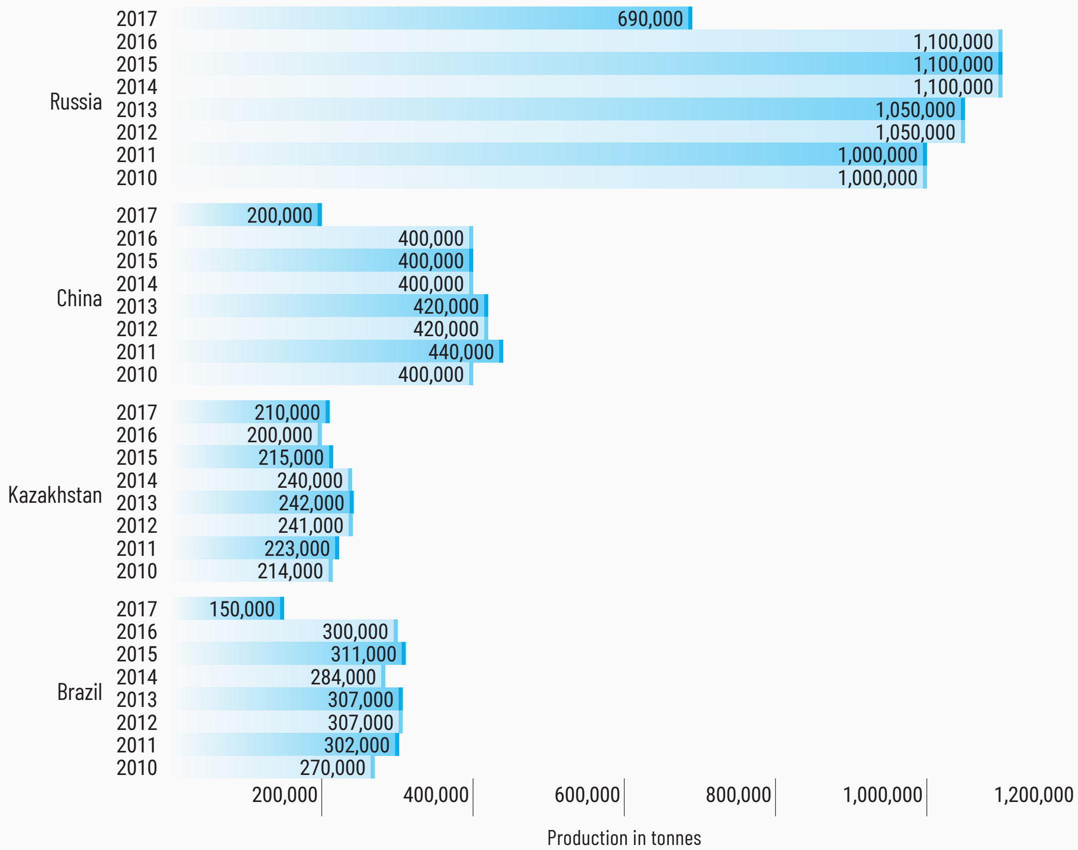
Plastics are polymers derived from fossil material (coal, natural gas, crude oil) and/or organic resources (cellulose, salt) and renewable compounds (grains, corn, potatoes, palm, sugar beet). During the manufacture and compounding of plastics other chemicals are used, including initiators, catalysts, solvents and a wide range of additives.

Global plastics production has increased exponentially since the 1950s (UNEP 2016b; Boucher 2017; Pravettoni 2018). While 1.5 million tonnes were produced in 1950 (Boucher 2017), in 2017 global production reached almost 350 million tonnes (Plastics Europe 2018). If

**Table 2.11** World production of rare earth mineral concentrates (thousand tonnes) and total estimated increase (per cent), 1990-2015 (Wietlisbach and Gao 2016)

| Year | Australia | China | US | Other | Total |
|---|---|---|---|---|---|
| 1990 | 6.1 | 16.5 | 22.7 | 14.7 | 60.0 |
| 2000 | 0.0 | 73.0 | 5.0 | 7.0 | 85.0 |
| 2010 | 0.0 | 120.0 | 1.0 | 3.4 | 124.0 |
| 2015 | 10.0 | 105.0 | 4.2 | 6.7 | 125.9 |
| **Total estimated % increase 1990-2015** | **63.9%** | **536.4%** | **-81.5%** | **-54.4%** | **109.8%** |

**Figure 2.10** **Asbestos mine production in the largest producer countries, 2010-2017 (tonnes) (based on USGS 2018b)**




current production and use trends continue unabated, annual global production is estimated to increase to about 2,000 million tonnes per year by 2050 (Pravettoni 2018) (Figure 2.11). Global production of plastic resins and fibres increased from 2 million tonnes in 1950 to 380 million tonnes in 2015, a CAGR of 8.4 per cent. About 7.8 billion tonnes of plastic resins and fibres were manufactured between 1950 and 2015. Half of this amount was produced in the past 13 years (Geyer, Jambeck and Law 2017).

**Figure 2.11** **Global and regional plastics production, 1950-2050 (million tonnes) (adapted from Pravettoni 2018)**

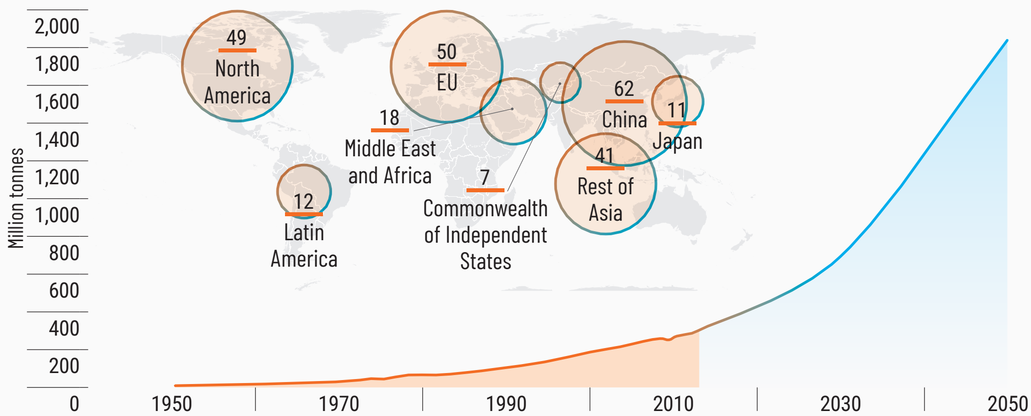
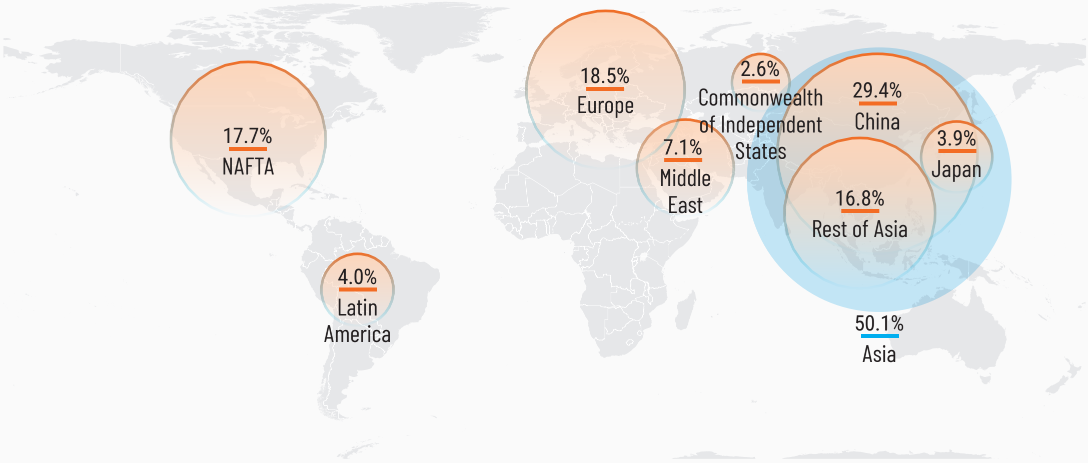


**Figure 2.12** **Distribution of global plastics production, 2017 (per cent) (adapted from Plastics Europe 2018, p. 19)**



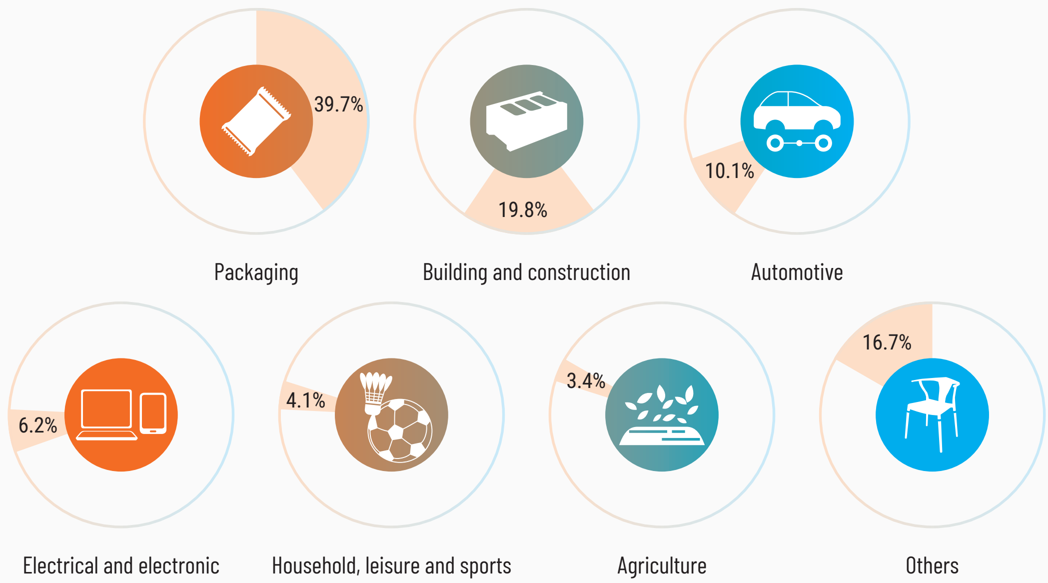

Includes thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants, and polypropylene fibres. Polyethylene terephthalate, polyamide and polyacrylic fibres are not included.

About half the world production of plastics occurs in Asia (Figure 2.12). Europe and North America (including Mexico) account for some 19 and 18 per cent, respectively (Plastics Europe 2018). China accounts for 28 per cent of global polymer resin and 68 per cent of global polymer fibre production (Geyer, Jambeck and Law 2017).

Many types of plastic are produced. Thermosets such as polyesters, epoxies and polyurethanes make up a significant share of the plastics market, but the largest share of the market is dominated by four main classes of thermoplastics: polyethylene (PE) (73 million tonnes in 2010), polyethylene terephthalate (PET) (53 million tonnes), polypropylene (PP) (50 million tonnes) and polyvinyl chloride (PVC) (35 million tonnes) (UNEP 2016b).

Plastics are used in a variety of downstream sectors (Figure 2.13). Durable products, ranging from construction materials to medical devices, make up nearly half the global plastics market, but packaging is the largest single application for plastics. Growth in the plastic packaging market has been stimulated by a global shift from

**Figure 2.13** Uses of plastic: main downstream sectors, 2017 (per cent) (adapted from Plastics Europe 2018, p. 24)




Others refers to medical equipment, plastic furniture and furniture equipment, technical parts used for mechanical engineering or machine-building, etc.

reusable to single-use containers, particularly in the prepared food, beverage and pharmaceuticals markets. Asia is the fastest growing region for plastic packaging currently and will be in the future, with the most rapid national growth taking place in China and India (Zion Research 2016).

There are strong vertical linkages between the oil and gas industry and plastic resin producers. At the feedstock level, plastic production is shifting from naphtha to low-cost natural gas. This means that ethylene, which had been conventionally produced with propylene as a co-product, can now be produced alone and firms reliant on propylene need to produce it separately. China, already the world's leading propylene producer, is building new production facilities to turn both oil and methanol (from coal) into propylene (Plotkin 2015).

### Primary microplastics are used in a variety of products and processes

Global plastics production also includes microplastics, very small plastic particles intentionally added to products or used in manufacturing processes to carry out a range of specific functions (Galloway 2015) (Box 2.1). Primary microplastics include capsules used to blast clean surfaces, plastic powders used in moulding, pellets used in plastic manufacturing process, microfibres in textiles, and plastic nanoparticles used in a variety of industrial processes (Gibb *et al.* 2017). Microplastics are also used in personal care and cosmetic products and, more recently, 3-D printing (UNEP 2016b).

### Production of bioplastics is growing, but remains a marginal share of the market

Bioplastics currently represent about 1 per cent of the about 335 million tonnes of plastic produced annually. However, global bioplastics production capacity is set to increase from around 2.11 million tonnes in 2018 to approximately 2.62 million tonnes in 2023 (Figure 2.14). Innovative biopolymers such as polylactic acid (PLA) and polyhydroxyalkanoates (PHAs) are the main drivers of this growth. Packaging is the largest field of application for bioplastics, at almost 65 per cent of the total bioplastics market (1.2 million tonnes) in 2018 (European Bioplastics and nova-Institute 2018).

**Box 2.1 Microplastics**

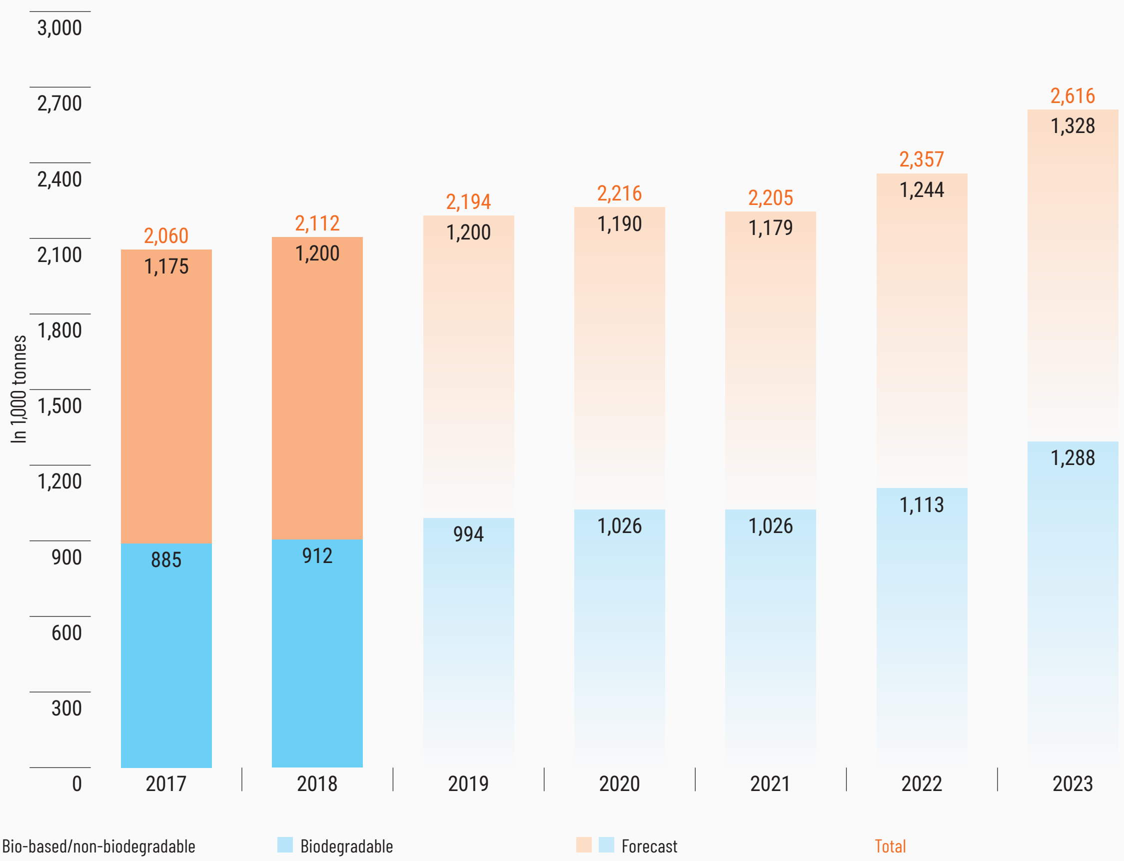
Microplastics are extremely small pieces of plastic. They are commonly considered to be micrometre-sized particles less than 5 millimetres (mm) in length (United States National Oceanic and Atmospheric Administration [US NOAA] 2018; Joint Group of Experts on Scientific Aspects of Marine Environmental Protection n.d.). This definition is used in some regulatory instruments (e.g. France, Ministry of Environment Energy and the Sea 2017).

There are two types of microplastics (Essel *et al.* 2015):

- *Primary microplastics* are directly manufactured as microscopic particles that are used in certain products and other applications.
- *Secondary microplastics* are fragments of macroscopic plastic materials which arise, for example, through the fragmentation of plastic bottles or the abrasion of tyres and textiles.

*Microbeads* are a type of primary microplastics that are intentionally added to cosmetics and personal care products (e.g. scrubs and toothpastes). Exfoliating agents, for example, may contain more than 10 per cent microbeads (Brande-Lavridsen n.d.).

**Figure 2.14 Global bioplastics production capacity, 2017-2023 (thousand tonnes) (adapted from European Bioplastics and nova-Institute 2018, cover page)**



# 3/ Megatrends and chemical-intensive industry sectors: risks and opportunities

## Chapter Highlights

Megatrends such as global economic shifts, urbanization and climate change have significant and diverse implications for chemicals and waste.

Megatrends affect the patterns of chemical production and consumption and may enhance exposure and related impacts; they also influence the direction and pace of innovation.

Driven by megatrends, many chemical-intensive industry sectors are growing, fuelling demand for chemicals.

Growth in chemical-intensive downstream industry sectors may create risks, depending on which technologies and chemicals of concern are used.

Downstream industry sector growth also creates opportunities for innovation towards improved production processes and safer products.

The evolution of the chemical industry is heavily influenced by (and needs to be understood within the context of) megatrends such as population growth, urbanization, globalization, digitalization and climate change. The implications of these megatrends for the sound management of chemicals and waste are discussed in the first section of this chapter. The chapter then turns to trends in chemical-intensive industry sectors, which create both risks and opportunities. While megatrends and industry sector trends are often global in nature, they may play out with important differences across regions.

## 3.1 Megatrends

### 3.1.1 The chemicals and waste dimension of megatrends

#### Megatrends and their implications for chemicals and waste

The future of the chemical industry is being shaped by many internal and external factors. All these factors exist in the context of large, long-term transitions or megatrends. Megatrends, which affect the economy and societies globally, can be defined as “large-scale, high impact and often interdependent social, economic, political, environmental or technological changes” (EEA 2015). To identify the megatrends influencing global development and innovation, particularly in relation to the chemical industry, 11 studies were assessed and synthesized for six key megatrends, shown in Table 3.1. These megatrends and their implications for chemicals and waste are examined in greater detail below. Other megatrends referred to in the literature

**Table 3.1** **Matrix analysis of megatrend studies**

| | Dugarova and Gülasan 2017 | UN General Assembly 2017 | National Intelligence Council 2017 | KPMG 2014 | EEA 2015 | Ernst & Young 2016 | Frost and Sullivan 2014 | OECD 2016 | Deloitte and VCI 2017 | Valencia 2013 | Global Manufacturing Industry Group 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Economic shifts | - | ○ | ○ | ○ | ○ | - | ○ | ○ | ○ | ○ | - |
| Technological change | ○ | ○ | ○ | ○ | ○ | - | - | - | ○ | - | ○ |
| Resource use, scarcity and competition | - | - | - | ○ | ○ | ○ | - | ○ | ( ○ ) | ○ | ○ |
| Demographic changes | ○ | - | - | ○ | ○ | - | - | ○ | ○ | ○ | - |
| Urbanization | - | - | - | ○ | ○ | ○ | ○ | - | - | ○ | ○ |
| Climate change, pollution | ○ | ○ | ○ | ○ | ○ | - | - | ○ | ○ | ○ | ○ |

include health, disease and well-being; the labour market; interconnectivity; consumption patterns; and poverty and inequality.

The megatrends discussed below (and others not treated here in depth) have implications for the sound management of chemicals and waste. They affect patterns of production and consumption in the chemical industry and downstream sectors. They also influence the direction and pace of innovation with respect to new chemicals and chemical applications (Valencia 2013; Whitesides 2015). Rapidly accelerating innovation may exacerbate current trends and create yet new challenges for chemicals management. However, these challenges may also provide new solutions, both to address legacies and to develop greener and more sustainable chemistry (Valencia 2013; Whitesides 2015).

## 3.1.2 Demographic changes

Demographic changes include growth in the total world population, greater life expectancy, and ageing populations in most countries. In 2017 the global population was nearly 7.6 billion. It is expected to reach 8.6 billion in 2030 and almost 10 billion in 2050. Africa is projected to have the fastest growing population during the next decades, with millions of new consumers. By

**Table 3.2** **World population prospects, (millions) (UN DESA 2017, p. 1)**

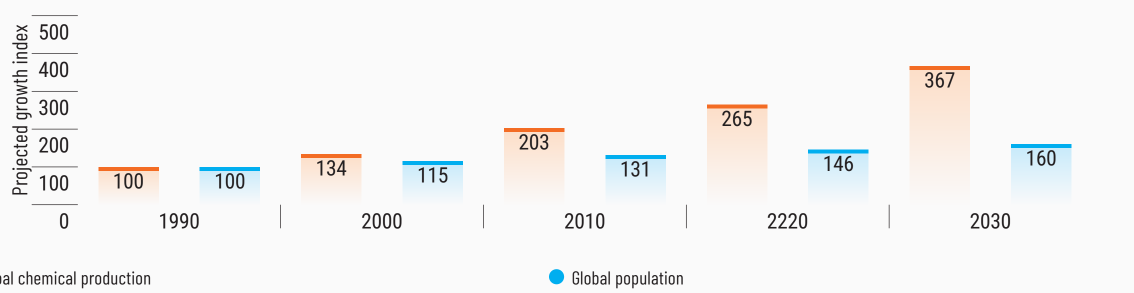
| Region | Population in millions | | | |
|---|---|---|---|---|
| | 2017 | 2030 | 2050 | 2100 |
| World | 7,550 | 8,551 | 9,772 | 11,184 |
| Africa | 1,256 | 1,704 | 2,528 | 4,468 |
| Asia | 4,504 | 4,947 | 5,257 | 4,780 |
| Europe | 742 | 739 | 716 | 653 |
| Latin America and the Caribbean | 646 | 718 | 780 | 712 |
| Northern America | 361 | 395 | 435 | 499 |
| Oceania | 41 | 48 | 57 | 72 |

2050 over one-quarter of the global population will live on the African continent (OECD 2016; United Nations Department of Economic and Social Affairs [UN DESA] 2017) (Table 3.2).

A growing population will drive demand for chemicals and chemical-intensive products. Under a business as usual (BAU) scenario, the rate of growth of chemical production is projected to exceed that of population growth at least until 2030 (Figure 3.1). This means per capita consumption of chemicals is increasing steadily, further amplifying the effect of population growth on demand for chemicals. These developments highlight the need to achieve sustainable consumption and production, as called for by Sustainable Development Goal 12 of the 2030 Agenda for Sustainable Development. They also reinforce the need to decouple material use from economic growth, enhance resource and eco-efficiency, advance sustainable materials management, and prioritize source reduction, reuse and recycling, as called for by the waste hierarchy.

A rapidly increasing population in Africa and Asia, along with the growing global middle class, are likely to lead to changing consumption patterns – from necessity-based to choice-based spending – which will increase demand for chemicals and cause resource scarcity, land use conflicts, and pressure on social and health care systems (Kharas 2017). At the same time, a relatively young and well-educated work force could lead to an increase in the number of scientists, researchers and innovators addressing present and future challenges (OECD 2016). An ageing population in developed countries will likely correspond to

**Figure 3.1** **Growth of basic chemical production capacity vs. population growth, 1990-2030 (based on UN DESA 2018 and Cayuela and Hagan 2019)**




The growth rates of chemical production capacity are derived from the past and projected growth rates for basic petrochemical building blocks (ethylene, propylene, butadiene, benzene, toluene and xylenes).

a shift in these countries from being economic powerhouses to being more socially and health care-oriented societies (UN DESA 2015), which is likely to increase demand for pharmaceuticals.

### 3.1.3 Global economic shifts

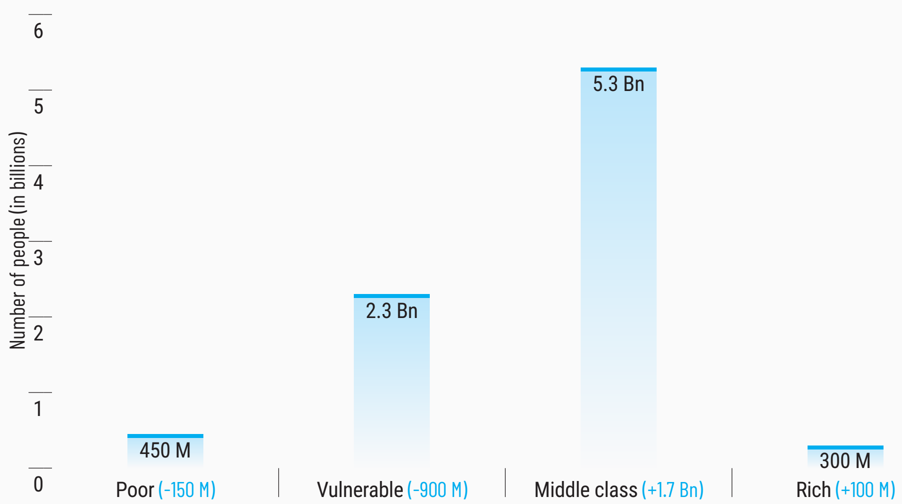
Profound economic shifts are taking place owing to dynamic global economic growth, especially in some emerging economies. While long-term projections come with uncertainties, the global economy could more than double by 2050. In 2050 six of the seven largest economies in the world are projected to be current emerging economies, led by China and India. At the same time, the EU is expected to lose a significant market share. Despite these dynamics, most of the largest developed countries are projected to continue to have higher per capita incomes than the emerging economies, although the gap will be closing (PricewaterhouseCoopers [PwC] 2017). Meanwhile, multinational corporations have grown to vast size: among the 100 largest economic entities worldwide, 31 are countries and 69 are corporations (Green 2016).

Economic growth is also driving the expansion of the global middle class, which accounts for the majority of demand in the global economy. The middle class accounts for approximately two-thirds of global household consumption and is growing more rapidly than other segments. It is estimated that by 2030 around 5.3 billion people will belong to the middle class, significantly more than to the other segments combined (Figure 3.2). Trends in the chemical industry reflect larger changes and increasing consumer purchasing power (Schulz, Rings and Forrest 2012). As explained in Part I, Ch. 1, chemical production and consumption have shifted to Asia.

### 3.1.4 Technological change

R&D efforts and expenditure, as well as the rate at which new technologies are adopted, have increased significantly in the past decades (DeGusta 2012; Arbesman 2016; United Nations Educational, Scientific and Cultural Organization Institute for Statistics [UIS] n.d.). A surge in innovation can be seen in the increasing number of patents, which has doubled since 2002 and surpassed 3 million in 2016 (WIPO 2017). North America is the largest investor in science, technology and innovation (OECD 2016) and many European countries rank among the world leaders in R&D expenditure (UIS n.d.).

**Figure 3.2** **Middle class dominance in 2030 (in billions) (adapted from Kharas and Hamel 2018)**




Note: Figures in parentheses indicate the increase/decrease in the number of people in each category by 2030 compared to 2018.

A related development is a shift in innovation capacities, including for chemistry innovation. The number of substances registered with the Chemical Abstracts Service has grown exponentially. It took 50 years to see the listing of 100 million substances, yet in the following two years another 30 million chemicals were registered. Since 1965 an average of one new substance has been registered every 2.5 minutes; by 2016 this rate increased to one new substance every 1.4 seconds. This increase in the number of new substances is likely to lead to greater complexity in chemical management.

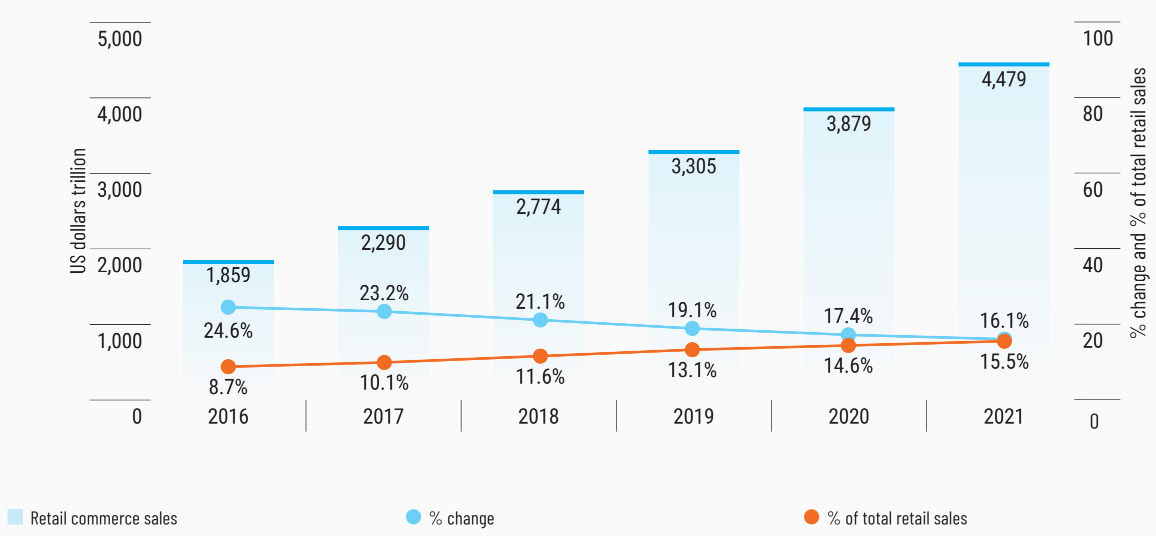
Digitalization is predicted to lead to profound changes in the chemical industry (Deloitte and German Chemical Industry Association [VCI] 2017; Klei *et al.* 2017). Data utilization will become increasingly important for value creation through further automation of manufacturing processes – allowing the use of advanced decision-making methods, realizing efficiency gains, and improving products and services for increased customer utility. This may offer opportunities for chemicals and waste management in, for example, the digitalization of agriculture, which includes the use of soil analysis sensors, drones and automated, data-driven steering systems to allow targeted application of fertilizers and pesticides (European Innovation Partnership for Agricultural Productivity and Sustainability 2017; Geisler 2018; OECD 2018).

The nature of the production and sales of goods and products is also undergoing fundamental changes. New business models, such as additive manufacturing (or 3-D printing; see Part IV, Ch. 4) and e-commerce are driving the decentralization of production and sales. Direct sales of chemical products via the internet are circumventing traditional distributors, many of which have management systems in place. Retail e-commerce sales may hit US dollars 4,479 trillion and surpass 16 per cent of total retail sales by 2021 (Figure 3.3). Cross-border e-commerce is growing by 25 per cent annually (DHL 2016).

### 3.1.5 Resource use, scarcity and competition

The increasing demand and competition for finite and increasingly scarce resources, including water, land, food and minerals, presents major challenges for the global community. For example, in the Asia-Pacific region rapid economic growth, intensified industrialization, urbanization and the changing lifestyles of a growing middle class have led to a sharp increase in natural resource use and consequently emissions of GHGs and other pollutants (Singhsachakul 2014).

**Figure 3.3** The growth of e-commerce, 2016-2021 (adapted from McNair 2017)



The complexity of this megatrend and its relevance for chemicals and waste can be illustrated by the interplay of growing food demand and water scarcity. Overall food production needs to increase by about 60 per cent between 2005/07 and 2050, while global water demand is projected to increase by 55 per cent (OECD 2016; FAO 2017). In most regions of the world over 70 per cent of freshwater is used for agriculture, and water withdrawals are projected to increase (Khokhar 2017). Depending on the practices used, growth in food demand is likely to increase the use of pesticides and fertilizers, which, in turn, may further aggravate water scarcity by polluting freshwater. Some regions are particularly affected. For example, agriculture accounts for around 23 per cent of exports from the Latin America and Caribbean region (Bárcena *et al.* 2015) and consumes double or triple the water volumes of countries in other regions (Cadena *et al.* 2017). Agriculture is the main economic sector in the Mashriq sub-region of West Asia, where water is a scarce resource. Discharges from marine desalination in the region are associated with chemical releases, including heavy metals (Alshahri 2017).

An innovative chemical industry has the potential to provide solutions to address challenges related to resource use and scarcity. It can be an engine for generating safe new materials and extending the life of existing ones as one way to reduce unessential production and consumption and the consequent demand for particularly scarce resources, thus making a contribution to waste prevention (Barra and Leonard 2018). There are also opportunities for the industry to substitute raw materials with renewable feedstocks, increasing the reuse and recycling of end user products, and to promote energy recovery and carbon utilization, which requires phasing out and substituting hazardous chemicals in manufacturing and in products (Accenture 2017; ECHA 2018).

### 3.1.6 Urbanization

Urbanization is taking place on a historically unprecedented scale. In 2008 for the first time, more people lived in cities than in rural areas. By 2050 an additional 2.5 billion people will move to cities, where 66 per cent of the global population will live. While 28 cities had more than 10 million inhabitants in 2014, by 2030 the number will increase to 41 (UN DESA 2014a) (Figure 3.4). With already relatively high rates of urbanization in North America (where 82 per cent of the population lives in cities), Latin America and the Caribbean (81 per cent) and Europe (74 per cent), the related dynamics are less discernible in these regions. On the other hand, the Asia-Pacific region (50 per cent) and

Africa (43 per cent) are still much more rural and increased urbanization has a much higher impact there: about 90 per cent of people who will be moving to cities by 2050 are (and will be) living in Asia-Pacific and Africa (UN DESA 2018).

The rate and scale of urbanization will likely lead to the need to develop accompanying infrastructure, including housing and transportation (UN DESA 2014b). This strong growth demands massive resources for construction purposes, as well as for maintenance and use by inhabitants, all of which will increase the use of chemicals. By 2050 China needs to create housing for 292 million new urban inhabitants, while in India 404 million people are expected to move to cities (UN DESA 2014a, p. 56). Urbanization also leads to changing needs in regard to employment and mobility, food and a healthy environment. Material consumption in the world's cities is expected to increase from 40 billion to 90 billion tonnes by 2050 (Swilling *et al.* 2018). Depending on the substances used in construction (e.g. for insulation), significant risks may emerge from a chemicals and waste perspective. New business opportunities for safer materials in the building sector may also emerge, however, for example following the regulation of asbestos in many countries.

### 3.1.7 Climate change and pollution

Global emissions of $CO_2$ and other GHGs continue to increase rapidly. In order of magnitude, fossil

**Figure 3.4** **Growth of the urban population by city size, 1990-2030 (adapted from UN DESA 2014a, p. 10)**

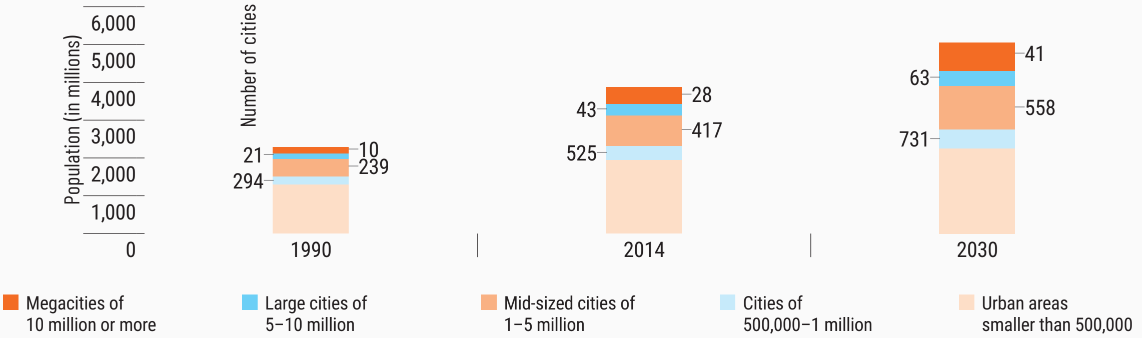
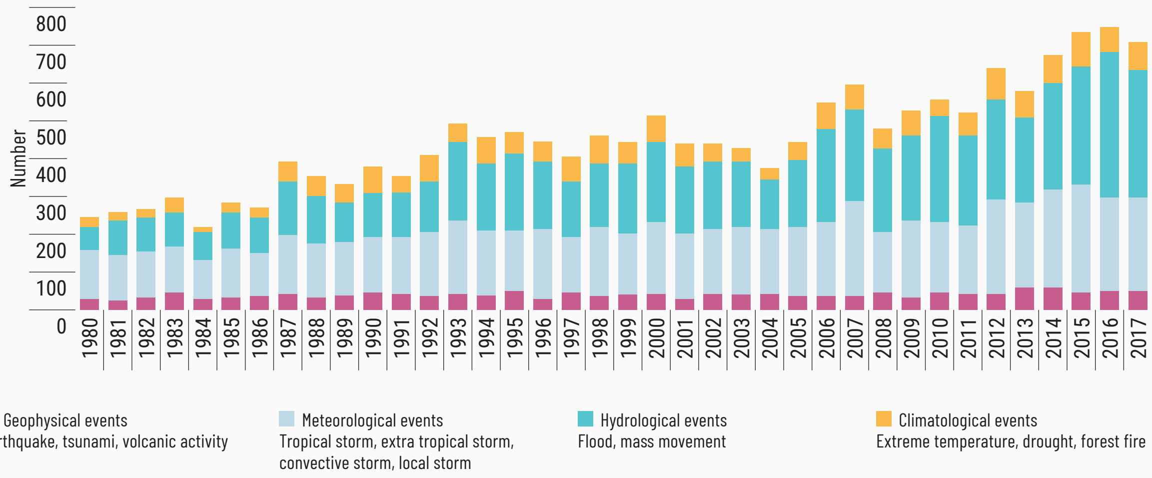


**Figure 3.5** Trends in the number of loss-relevant natural events, 1980-2016 (adapted from Munich Re 2017)




fuel combustion and agriculture are among the largest sources of $CO_2$ emissions (OECD 2016). The chemical industry is a significant source of pollution and contributor to GHG emissions (see Part I, Ch. 5). Global warming also leads to the remobilization of pollutants such as POPs due to melting glaciers and thawing permafrost (Grannas *et al.* 2013). Moreover, climate change may affect pesticide use (i.e. in the form of higher amounts, doses and frequencies, and different varieties or types of products applied) (Delcour, Spanoghe and Uyttendaele 2015). Chemical accidents are frequently caused by natural disasters and weather-related events (see Part I, Ch. 5), adding another dimension to the increase in the frequency of climate-related loss events (Hoeppe 2016) (Figure 3.5). Three out of five of the countries most affected by the impacts of weather-related loss events between 1996 and 2015 are in Latin America and the Caribbean.

The chemical industry can also help reduce pollution, not only through improving resource efficiency in the chemicals sector but also by supporting innovations leading to materials and products which can reduce emissions of $CO_2$ and other pollutants in many other sectors or, for example, by providing innovations for carbon capture and storage. Biotechnology can make a positive contribution to the reduction of the negative health and environmental impacts of the petroleum and petrochemicals industries through the development of bio-based batteries for e-mobility, as well as through research on artificial photosynthesis processes and microorganisms for biofuel production.

## 3.2 Chemical-intensive industry sectors

### 3.2.1 The chemicals and waste dimension of industry sectors

#### Chemicals are used across industry sectors

The chemical industry is an important backbone of various downstream industry sectors such as electronics, agriculture, pharmaceuticals, construction, textiles, transportation and energy. It supplies raw materials, feedstocks and speciality chemicals to each of these sectors. Table 3.3 provides an overview of the primary commodity chemical groups used in chemical-intensive downstream sectors (or "end markets").

#### Megatrends and industry sector trends create risks and opportunities

Many chemical-intensive industry sectors are expected to grow, responding to the dynamics of global megatrends. In turn, growth in chemical-intensive industry sectors and markets continues to drive growth in the markets for chemicals used in these sectors. This includes construction,

**Table 3.3** Major end markets for four primary commodity chemical groups (adapted from Bamber, Frederick and Gereffi 2016, p. 18)

| | **Petrochemicals:** Polyethylene, polyprolylene, polyvinyl chloride, polystyrene | **Industrial gases:** Oxygen, nitrogen, argon, hydrogen, acelyne, $CO_2$ | **Inorganic chemicals:** Caustic soda, hydrochloric acid, liquid chlorine, sulphuric acid, chlorine, sodium hypochlorite, ferric chloride, titanium dioxide | **Oleochemicals:** Fatty acids, fatty alcohol, methyl esters, glycerine |
|---|---|---|---|---|
| Agriculture | | o | o | |
| Automotive | o | | | |
| Construction | o | o | | o |
| Personal care & detergents | | o | o | o |
| Electronics | o | o | o | |
| Food & Beverage | | o | o | o |
| Manufacturing | | o | o | |
| Packaging | o | | | o |
| Pulp & paper | | o | o | o |
| Pharmaceutical | | | | o |
| Textiles & apparel | o | | | o |
| Water and waste treatment | | o | o | |

**Table 3.4** End markets for chemicals (adjusted based on Global Manufacturing Industry group, 2011, p. 18)

| | **End market size and chemical revenue from end market** | | **Megatrends likely to have the most significant impact** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chemical revenue (US dollars billion) | End market size (US dollars billion) | Resource scarcity | Green/ sustainability | New pattern of consumption | Demographic change | Conver-gence of technologies | Urbanization | Human health | Patterns of mobility |
| Construction | 695 | 8,016 | o | o | | o | o | o | | |
| Electronics | 371 | 2,458 | o | | o | | o | o | | o |
| Household | 159 | 800 | | o | o | o | o | o | o | |
| Agriculture | 142 | 1,772 | o | o | o | o | | | o | |
| Paper and packaging | 130 | 702 | | | o | | o | | | |
| Automotive | 128 | 1,932 | o | o | | | o | o | | o |
| Health care | 113 | 1,368 | | | o | o | o | | o | |
| Energy | 113 | 3 833 | o | o | | | o | | | |
| Transportation | 61 | 1,023 | o | o | | | | o | | o |
| Nutrition | 29 | 4,022 | o | | o | o | o | | o | |
| Personal care | 20 | 225 | | o | o | o | | | o | |
| Machinery | 15 | 457 | | | | | | o | | |
| Apparel and textiles | 11 | 1,097 | | | | o | o | o | | |
| Mining and metals | 4 | 1,333 | o | o | | | | | o | |

electronics, agriculture, pharmaceuticals, energy, transportation and textiles (discussed in this chapter), as well as other sectors such as mining and cosmetics. These chemical-intensive downstream sectors vary considerably in terms of the size of the respective industry, as well as the types and volumes of chemicals used. An overview of the size of the end markets and the chemical revenue in each end market is presented in Table 3.4, which also indicates megatrends that are likely to have the most significant impacts on the respective sectors. Construction is the largest end market and is also the sector generating the largest chemical revenue.

Industry sector growth creates opportunities for innovation, such as replacing chemicals of concern with safer chemicals or non-chemical alternatives. However, growth may also increase risks when old technologies that are dependent on chemicals of concern are used even when adequate risk management measures are not in place. In some cases, conflicting objectives may play a role, such as use of better insulation to save heating energy leading to higher emissions of facade coatings (biocides) to the environment, which then need to be reduced (Burkhardt *et al.* 2011).

### 3.2.2 Construction

The global construction sector is expected to grow by 3.5 per cent annually, with its chemicals market projected to grow by 6.2 per cent annually between 2018 and 2023 (Mordor Intelligence 2018). This growth will primarily be driven by the rapidly urbanizing Asian and African regions (UN DESA 2014a). It is estimated that the United States, China, India, Indonesia, the United Kingdom, Mexico, Canada and Nigeria will account for 70 per cent of global construction growth by 2030, with India the fastest growing market (Global Construction Perspectives and Oxford Economics 2015). The global market for construction chemicals (comprising concrete admixtures, protective coatings, asphalt modifiers, adhesives and sealants) is expected to grow by 9 per cent per year and increase to more than US dollars 50 billion by the end of 2024 (Global Market Insights 2017).

Some of the chemicals used in construction cause severe harm to workers on construction sites. These chemicals can also affect the health of future building occupants and office workers as a result of indoor air pollution. In developing countries asbestos use for construction remains a serious hazard. The World Health Organization (WHO) has estimated that 125 million people in the world are exposed to asbestos in the workplace and that 107,000 die each year due to diseases caused by occupational exposure to asbestos (WHO 2014). PVC materials are a major source of indoor chemical residues of substances such as DEHP, which have, for example, been linked to asthma (Jaakkola and Knight 2008; Kanchongkittiphon *et al.* 2015). Plastic is a widely

used construction material: about 21 per cent of the 47 million tonnes of plastic used in Europe goes into the construction sector (Plastics Europe 2012). Labour- or technology-intensive sorting is needed in order to obtain a high quality recyclate from construction waste (Hahladakis *et al.* 2018). There are also concerns about lead exposure during the demolition, retrofit or renovation of older buildings, both in occupational and residential (do-it-yourself) settings (US EPA 2011).

There are many opportunities to use safer chemicals in construction, particularly for siding and roofing materials, structural members, insulation and coatings. There are also opportunities to use safer chemicals in information technologies, particularly those that integrate sustainability criteria into material selection decision-making (Agarwal, Chandrasekaran and Sridhar 2016). The global green building materials market is expected to grow from 2016 to 2022 at a CAGR of 11.9 per cent (Prasad and Sinha 2016). Stronger incorporation of recyclability criteria in choosing construction materials provides additional opportunities (Zimmann *et al.* 2016).

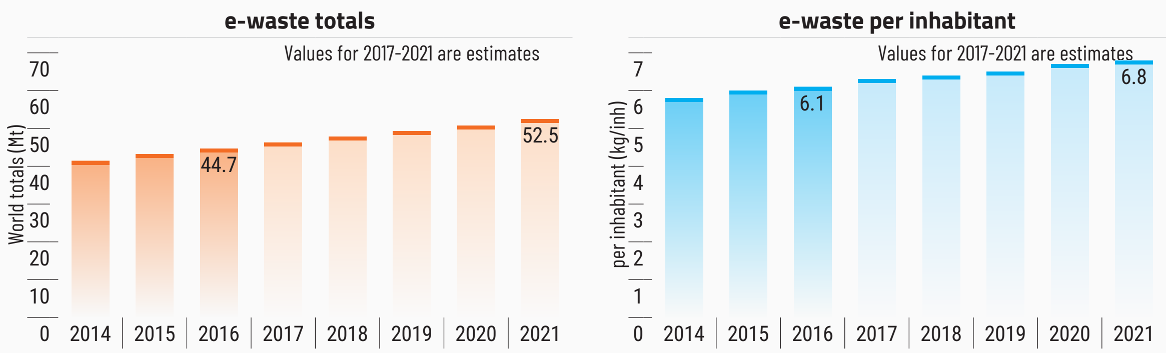
### 3.2.3 Electronics

The consumer electronics market continues to grow rapidly. The top producing regions are Asia (73 per cent), the Americas (12 per cent) and Europe (14 per cent). The top three countries in terms of output and market share are China (51 per cent), the United States (10 per cent) and Japan (7 per cent) (ZVEI 2017). More than half of global electrical and electronic product production takes place in China. Investment in electronics manufacturing in India is increasing at a CAGR of 27 per cent and could reach US dollars 104 billion by 2020. For almost all electrical and electronic products, chemicals are essential. It has been estimated that the global electronic chemicals and materials market will grow to US dollars 30.5 billion by 2020, compared with US dollars 22 billion in 2014 (McWilliams 2016).

Electronic and electrical products contain a number of hazardous substances including lead, mercury and other metals, flame retardants and certain phthalates (Nimpuno and Scruggs 2011). There are risks of exposure to harmful chemicals during production and end-of-life recycling, when e-waste is informally scrapped to obtain valuable material (Perkins *et al.* 2014). In 2016, 44.6 million tonnes of electronic waste were generated (Figure 3.6), of which 80 per cent was handled illegally (Baldé *et al.* 2017). Workers in the supply chains of developing countries are particularly at risk of exposure to these chemicals due to the unregulated nature of the electronic waste (e-waste) recycling sector (Lundgren 2012). While informal e-waste operations are among the world's most hazardous occupations (Pure Earth and Green Cross Switzerland 2016), exposure to toxic substances is common even in formalized e-waste recycling in developed countries (Julander *et al.* 2014).

Opportunities exist for the safer design of products for longevity and ease of recycling, as

**Figure 3.6** **Global e-waste generated by volume and per inhabitant, 2014-2021 (adapted from Baldé *et al.* 2017, p. 5)**



well as for using "products as service" to make the sector more sustainable. The value of the raw materials in all e-waste is estimated to be around US dollars 55 billion (Baldé *et al.* 2017). The Apple GiveBack programme, Dell's laptop line that uses post-industrial recycled carbon-filled polycarbonate, and Samsung's cadmium-free high-definition televisions are examples of electronic companies' initiatives aimed at greater sustainability (Stanislaus 2017).

### 3.2.4 Agriculture and food production

Agriculture and food production are chemical-intensive. Output will increase considerably in the coming decades due to the growing global population and changing, more resource-intensive diets (UN DESA 2017). The FAO estimates that overall food production needs to increase by about 60 per cent between 2005/07 and 2050 (FAO 2017). This demand, and increasing pressure on farmland, will lead to significant growth of the agrochemicals market, which had a value of US dollars 215.18 billion in 2016 and is projected to reach US dollars 308.92 billion by 2025 (Grand View Research 2017). However, the increasing trend of organic agriculture and agroecology in many countries may affect this forecast growth. The Asia-Pacific region accounts for the largest share of the global agrochemicals market, with China and India as major consumers. Latin America is expected to have the highest growth rate, with Brazil and Argentina being significant markets (Reuters 2018).

While agrochemicals have helped to significantly increase food production, the use of pesticides and fertilizers has nevertheless caused widespread adverse impacts on soils, ecosystems and human health (Carvalho 2017). Exposure to some pesticides has adverse effects on humans, including reproductive disorders and cancers as well as acute poisonings, and pose threats to biodiversity (Kim, Ko and Lee 2013; Hallmann *et al.* 2017; Rim 2017). Pesticide use varies significantly across countries (FAO 2018) (Figure 3.7). Moreover, excessive use of nitrate-based fertilizers may lead to ground and surface water contamination (Liu *et al.* 2014). Agriculture remains the largest economic sector in terms of contribution to gross domestic product (GDP) and employment in Africa (African Development Bank [ADB], OECD and United Nations Development Programme [UNDP] 2017), which presents challenges regarding exposure to certain agrochemicals and the management of stockpiles of obsolete chemicals.

Biological alternatives to synthetic or chemical fertilizers and pesticides are in increasing demand. The global biological crop protection market is forecast to grow at a CAGR of 11.33 per cent during 2016-2021 (Business Wire 2016). This shift in the consumer market offers opportunities for

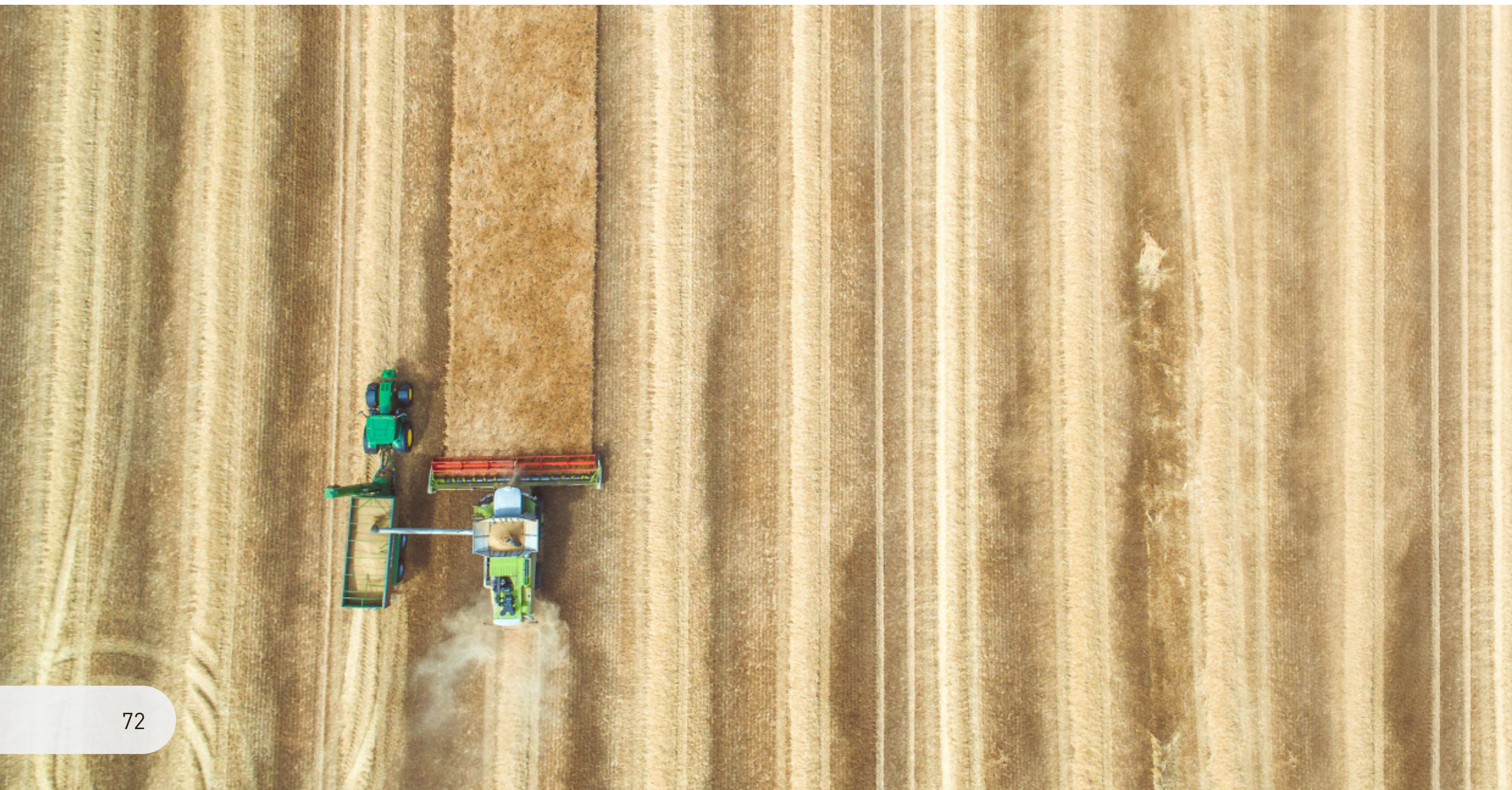
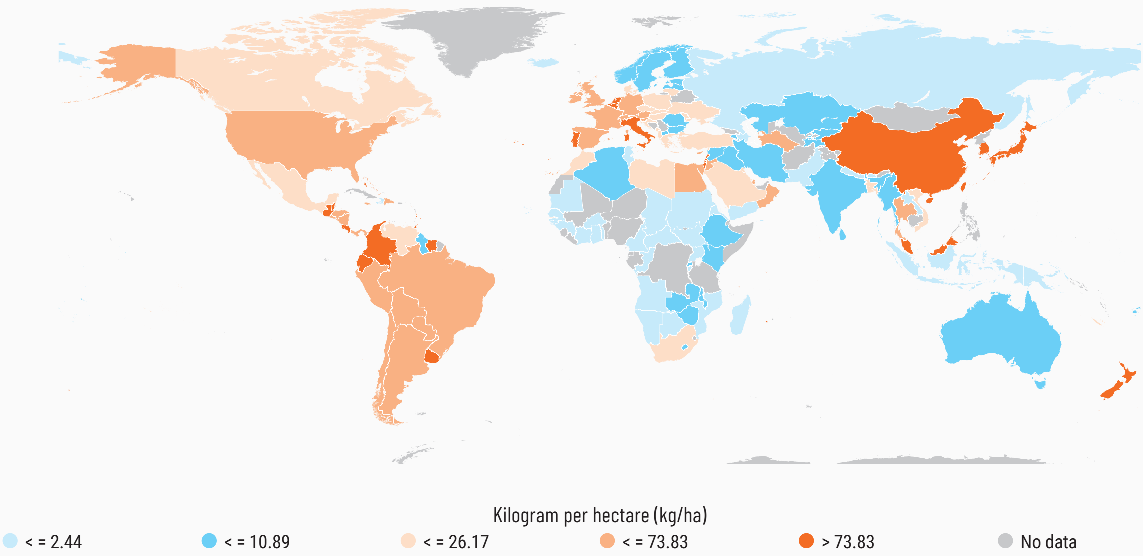


**Figure 3.7** Use of pesticides per area of cropland, kg/ha, sum 2006-2016 (adapted from FAO 2018)




new chemical nutrients and plant protection biologicals. In 2016 the global organic food market was worth US dollars 110.25 billion and it is projected to grow to US dollars 262.85 billion by 2022 (Produce Marketing Association Research 2017). However, in these areas it is important to assess the alternatives' hazard properties and potential adverse impacts, including on other ecosystem services, in order to avoid regrettable substitution. Significant opportunities also exist to scale up Integrated Pest Management (IPM) and agroecological approaches, including the development and use of non-chemical alternatives and other good agricultural practices.

### 3.2.5 Pharmaceuticals

Global spending on medicine is projected to reach nearly US dollars 1.5 trillion by 2021, about US dollars 370 billion higher than in 2016. The total volume of medicines consumed globally will increase by about 3 per cent per year through 2021. In 2016 North America accounted for 49 per cent and Europe for 21.5 per cent of world pharmaceutical sales (QuintilesIMS 2016). North America is also among the regions with the greatest number of pharmaceuticals detected in its water sources (Owens 2015). Pharmaceuticals research, development and production capacities are growing quickly in emerging economies such as Brazil, China and India. "The number of new medicines reaching patients will be historically large, with 2,240 drugs in the late-stage pipeline and an expected 45 new active substances (NAS) per year forecast to be launched on average through 2021" (QuintilesIMS 2016).

From a chemicals and waste management perspective, environmental and health concerns in this sector are primarily related to releases of pharmaceuticals to the environment, where they can lead to detrimental effects, especially on aquatic life, or contribute to antimicrobial resistance (Owens 2015; see also Part I, Ch. 5, 7; Part II, Ch. 4). Sources of releases of pharmaceuticals to the environment include direct emissions from drug manufacturing, patient and animal excretion, and disposal of unused or expired medicines (Larsson 2014; Some of Us 2015; Changing Markets Foundation and Ecostorm 2016; Nordea 2016; Access to Medicine Foundation 2018; Health Care without Harm Europe 2018). Workers engaged in the manufacture of pharmaceuticals may be at risk due to occupational exposure to harmful chemicals; nearby communities and ecosystems may also be at risk because of pharmaceutical discharges (Gathuru *et al.* 2015; Nordea 2016; Changing Markets Foundation and Nordea 2018). Given the critical role of pharmaceuticals in human and veterinary health, addressing chemicals and waste issues in this area requires careful balancing and consideration of potential trade-offs.

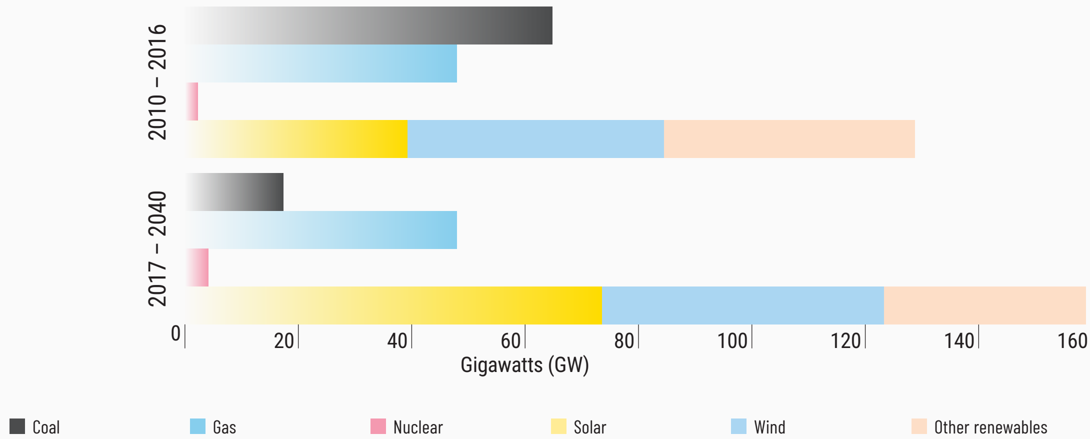
The pharmaceutical industry has been described as moving towards the development of more efficient, less polluting processes, the use of less hazardous reagents, and the development of improved catalysts American Chemical Society (2015). Companies such as Pfizer and Merck have developed new biocatalytic processes for their drugs Lyrica and Januvia, respectively, that decrease the use of solvents as well as the organic chemical waste produced (Sharma 2015). Founded on the principles of product stewardship and a life cycle perspective, the ECO-Pharmaco-Stewardship (EPS) initiative has been developed to identify the potential environmental risks of pharmaceutical ingredients; improve manufacturing effluents management; and use extended environmental risk assessments (EFPIA 2016). Substitution of viscosity and binding agents in pharmaceuticals with alternatives that have lower environmental impacts (e.g. the use of starch-based polymers) is another promising area for innovation (Kadajji and Betageri 2011). Governments could take action, for example, through regulations and fiscal incentives to promote green and sustainable pharmacy.

### 3.2.6 Energy

Global energy demand is projected to increase nearly one-third by 2040 despite a slowdown in demand growth due to energy efficiency regulations (IEA 2017). India and China – currently the world's largest consumers – are expected to account for the largest share of the increase in primary energy demand. Overall, developing countries in Asia will account for two-thirds of global energy growth, with the remainder coming mainly from the Middle East, Africa and Latin America (IEA 2017). Key trends in the global energy system include the rapid advance of renewable energy (IEA 2017) (Figure 3.8) and increasing electrification of energy. It is estimated that one-third of the world's new wind power and solar photovoltaic technology will be installed in China. Among industrial activities, the chemical sector is expected to see the highest growth in energy demand at around 45 per cent between 2015 and 2040.

Hazardous chemicals used in renewable energy solutions may pose threats to human health and the environment and create future legacies. For example, carcinogenic chemicals such as cadmium and lead are used in the manufacture of solar panels (Aman *et al.* 2015). With many first-generation solar panels nearing their end of life, the challenge of adequate disposal comes to the forefront. A similar spectre is being raised about the future management of energy storage provisions. As regards wind power, it has been estimated that by 2040 more than 400,000 tonnes of composite material per year from blades will have to be disposed (Ramirez-Tejeda, Turcotte and Pike 2016). Currently there are

**Figure 3.8** Global average annual net capacity additions by type of energy (gigawatts), 2010-2016 and 2017-2040 (adapted from IEA 2017)




no established recycling solutions for the large amounts of blades that have reached the end of their life (Liu and Barlow 2017).

Chemicals will play a central role in incorporating resource efficiency and climate friendliness in energy generation, storage, distribution and use. Chemistry is essential to the development of innovative battery technologies, wind turbines and solar panels, among others, for example by providing resins for blades and coating materials used in wind turbines or sealants for PV panels (ICCA 2017). Chemistry innovations can help decrease the costs of renewable energy solutions and increase their durability (e.g. through novel polymers used in wind turbines) (Scott 2017). The global market for energy efficiency technology is expected to grow from US dollars 995 billion in 2017 to US dollars 1,781 billion by 2025. It is estimated

**Box 3.1** Lead-acid batteries: avoiding future legacies

In 2018, around 86 per cent of all lead was used in the production of lead-acid batteries, whose primary use is in conventional vehicles (ILZSG 2019). The growing market for automobiles in low- and middle-income countries is expected to lead to an increasing number of lead-acid batteries. The total annual generation of used lead-acid batteries (ULABs) in Africa is estimated to amount to more than 1.2 million tonnes (Tür, Manhart and Schleicher 2016).

When conducted informally or without proper pollution and occupational health and safety controls, recycling of ULABs can be highly polluting. Globally, 1.9 million people are at risk from severe damage to their health from lead exposure due to unsound lead-acid battery recycling (Daniell *et al.* 2015; Pure Earth and Green Cross 2016). The often informal operations in many low- and middle-income countries pose severe health risks, especially to children (Haefliger *et al.* 2009; García and Marín 2016) while implying a high burden of disease predominantly in Southeast Asian countries but also in China (van der Kuijp, Huang and Cherry 2013), Africa and Latin America. A 90-country study estimated that from 10,599 to 29,241 informal lead-acid battery processing sites were putting the health of as many as 16.8 million people at risk in 2013 alone (Ericson *et al.* 2016).

As an alternative to lead-acid batteries, lithium-ion batteries are also expected to pose a quickly growing environmental and health challenge in coming decades with their own specific recyclability challenges (Lv *et al.* 2018), particularly the very diverse mix of compounds that are not easily separated (Gaines 2014). Innovation needs to be encouraged not only in order to develop cheaper batteries with higher capacities, but also to design them to be more sustainable throughout their life cycle with a special focus on end-of-life and recyclability (Larcher and Tarascon 2015).

that the global market for environmentally friendly technology for the generation, storage and distribution of energy will nearly double in the same period (Berger *et al.* 2018). Extended producer responsibility systems for batteries would minimize the risk that batteries will end up in informal recycling operations or dump sites.

### 3.2.7 Transportation

Although the global transportation sector has experienced relatively low growth rates in recent years, it is likely to continue growing (KPMG 2017). Passenger transport is projected to more than double by 2050. Low growth rates are projected in OECD countries, with most of the increase expected in Asia (OECD and International Transport Forum [ITF] 2017; PwC 2018). Urbanization, population growth and a growing middle class (particularly in emerging economies) are expected to lead to continuous growth in car sales at around 2 per cent per year (Hannon *et al.* 2016; Pucher and Buehler 2017). The World Bank (2018) has estimated that there will be twice as many vehicles on the roads by 2050 than the 1 billion in 2015. Non-urban transport (particularly aviation) is expected to grow strongly, while construction of rail networks is also projected to grow. Freight transport may triple by 2050 (OECD and ITF 2017).

Air pollution, particularly that due to road traffic via particulate matter and sulphur emitted by diesel motors, is a significant health and environmental concern (UNEP 2017). Growth in the transport sector also presents challenges from a chemicals management perspective. Lithium-ion batteries containing heavy metals and other toxins are expected to pile up after their use in electric vehicles (Stanway 2017). Lead-acid batteries used in combustion engines also present a risk, particularly during recycling (Daniell *et al.* 2015) (Box 3.1).

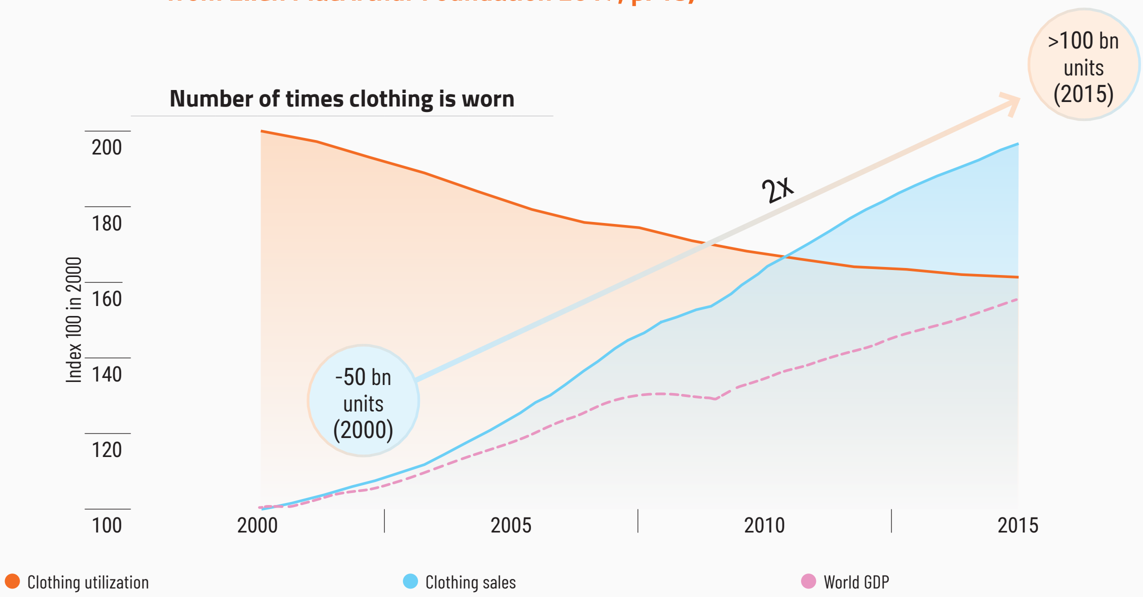
The shift from internal combustion to electric motors will have mixed implications: an increase in volume is expected for battery materials and polymers, while demand for lubricants, catalysts, fuel additives and automotive fluids is expected to decrease (Kumpf, Eliaz and Aldred 2018). Green and sustainable chemistry opportunities exist for lighter weight materials and high-performance polymers in vehicle construction (BASF 2013). Opportunities for more sustainable materials and technologies also exist in the paving industry. Some have already found their way onto the market, such as recycled asphalt pavement or warm mix asphalt technology (Huang *et al.* 2017).

### 3.2.8 Textiles

The global textiles sector has doubled in production over the last 15 years (Ellen MacArthur Foundation 2017) and the annual retail value of apparel and footwear is expected to increase by 30 per cent between 2017 and 2030 (Eder-Hansen *et al.* 2017). A key driver is a phenomenon known as “fast fashion”, characterized by quick turn-arounds of new styles, a larger number of collections offered per year, and lower prices coupled with a lower cloth utilization rate (Ellen MacArthur Foundation 2017) (Figure 3.9). The Asia-Pacific textile chemicals industry is expected to experience the fastest growth while China is likely to remain the world’s largest manufacturer of textiles and apparel, although many garment makers are exploring new manufacturing facilities in other Asian countries. Bangladesh, Viet Nam and India have large textile industries. Ethiopia is projected to become a fast-growing manufacturing hub in Africa (Berg, Hedrich and Russo 2015). Several other African countries are expected to expand their garment and textile industry as part of national industrialization strategies (ADB, OECD and UNDP 2017).

A growing textile industry leads to an increase in the chemicals used in textile processing, the market value of which is estimated to be US dollars 31.8 billion by the end of 2026 (Transparency Market Research 2018). For example, increased demand for weather-resistant textiles may, depending on the chemicals and technologies used, increase the use of PFASs. When washed, some garments release plastic microfibres, 0.5 million tonnes of which leak into oceans each year. Less than 1 per cent of the material used to produce clothing is recycled into new clothing, representing a loss of over US dollars 100 billion worth of materials each year (Ellen MacArthur Foundation 2017). The World Bank has estimated that 20 per cent

**Figure 3.9** **Growth of clothing sales and comparison with declining clothing utilization (adapted from Ellen MacArthur Foundation 2017, p. 18)**




Refers to the average number of times a garment is worn before it ceases to be used.

of industrial wastewater pollution worldwide originates from the textile industry (Kant 2012). 73 per cent of clothing ends up in landfills or is incinerated at the end of their life. Hazardous chemicals can leach out as textiles degrade in landfills, while incineration can lead to harmful emissions. It has been estimated that eliminating the negative health impacts emanating from poor chemicals management in the textile industry would yield an economic benefit of around US dollars 8 billion per year (Eder-Hansen *et al.* 2017).

Regulatory restrictions, increasing consumer concern, civil society campaigns (e.g. DETOX, Greenpeace) and industry-driven initiatives such as Zero Discharge of Harmful Chemicals (ZDHC 2018) drive innovation in the industry. Leading brands have introduced sustainable collections without harmful chemicals, and with low water and carbon footprints (Ellen MacArthur Foundation 2017). Sustainable textile fibres such as hemp, sisal and jute are becoming popular. The ecofibre market is estimated to grow, with a CAGR of more than 10 per cent by 2022 (Technavio 2018). Other opportunities for innovation include safer textile chemistries and advanced technologies for chemical recovery from wastewater (Sustainable Business 2013).

# 4/ Global supply chains, chemicals in products, and circularity

## Chapter Highlights

Chemicals fulfil various performance functions in materials and products; they are also widely used in auxiliary processes, manufacturing, waste treatment and other areas.

Modern-day products contain a large number of chemicals at varying concentrations; unintentional contaminants are present in a range of products.

Hazardous chemicals in secondary raw materials create specific challenges for recycling and for a circular economy.

Complex chemical and product supply chains span the globe; adverse effects may occur at various stages in the life cycle, including manufacturing, consumption, reuse and disposal.

Understanding and managing chemicals in global supply chains is critical to advance sustainable consumption and production; a holistic life cycle perspective is essential to avoid burden shifting.

While the international community has been paying significant attention to the management of individual chemicals, momentum is growing to better understand the complexities associated with chemicals in products and product life cycles, as well as the sustainability dimensions. This chapter sheds light on the interface of chemical and product supply chains, within the broader sustainable consumption and production system. Some of the concepts introduced, such as life cycle assessment and sustainable supply chain management, are further discussed in Part III, Ch. 7 and Part IV, Ch. 6.

## 4.1 The complexity of global supply chains and management challenges

### Global trade of chemicals and products

The evolution of global value chains has significantly affected global trade and supply chains for chemicals and products. Business between companies around the world involves trade in chemicals, materials, and intermediate and final products at various stages of their life cycle, including waste. The trade of chemicals such as benzene, methanol and sulphuric acid

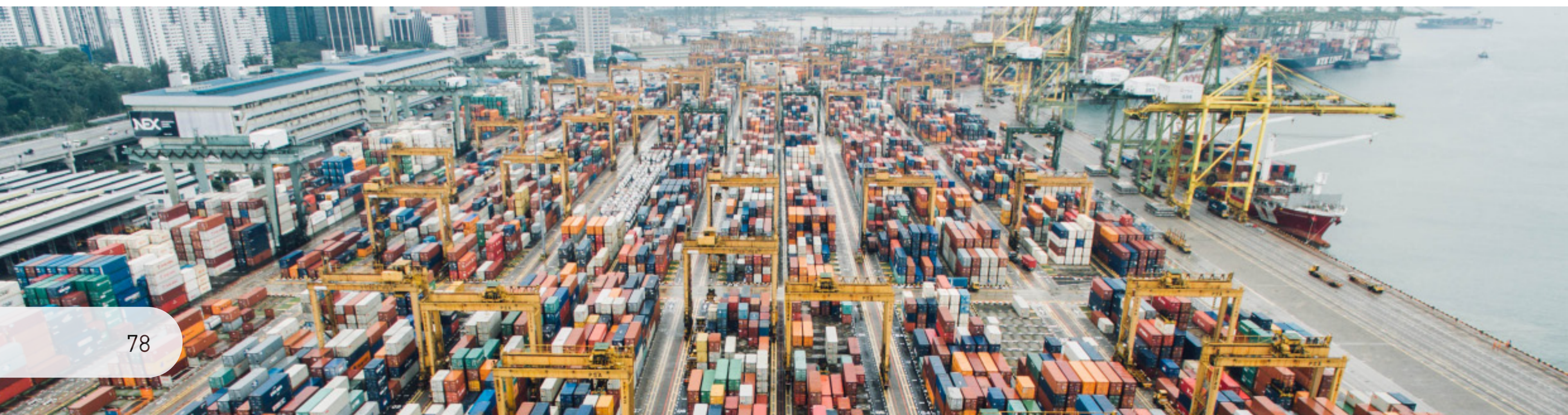
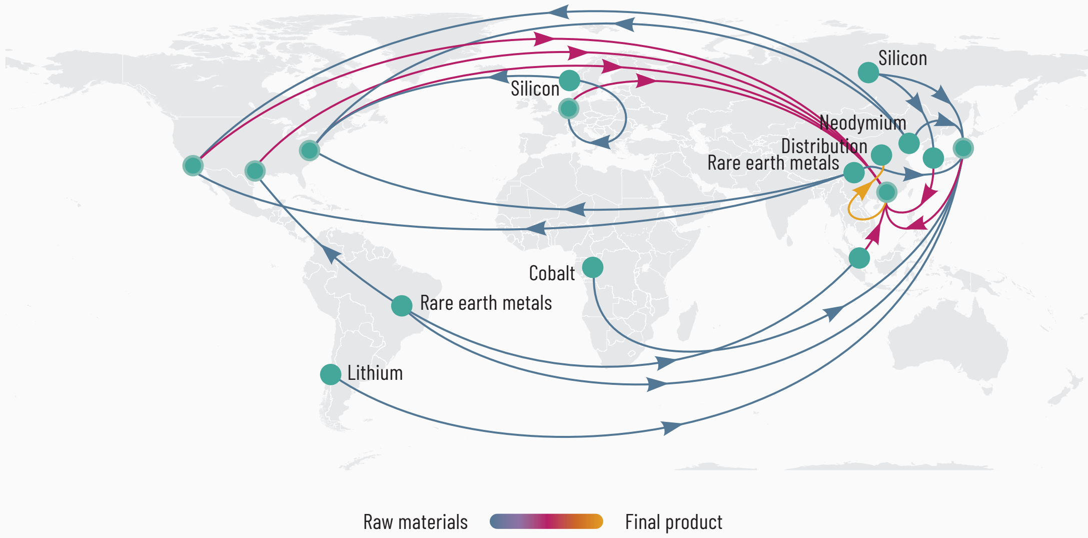


**Figure 4.1** **Illustration of the complexity of global supply chains: the case of an electronic product (adapted from Sourcemap 2012)**

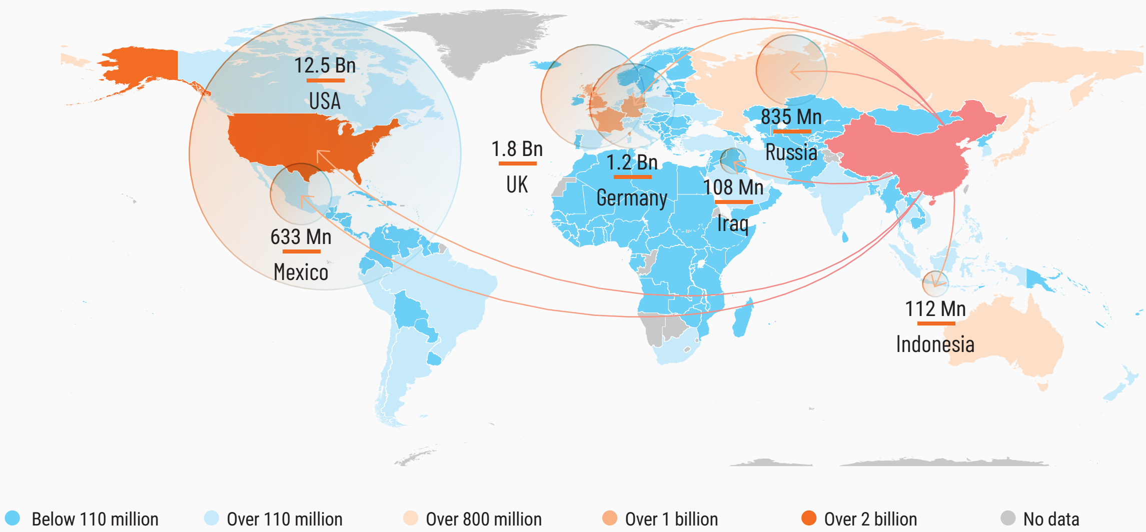



Chemical-intensive products, such as the electronic product depicted here, are traded through increasingly complex global supply chains, spanning many countries and regions. This poses a variety of management challenges.

has increased significantly in the past decades (Chua 2017). This adds further to the complexity of supply chains, particularly where imported chemicals are used in the production of articles and products which are then exported, or where products are recycled and materials are returned to exporting countries for re-manufacturing. This complexity of global supply chains, and the cross-border trade of chemicals and chemical-intensive products across countries with distinct regulatory frameworks, create challenges. The supply chain for electronics illustrates fragmentation in a specific economic sector and across geographic locations (Figure 4.1).

Figure 4.2 shows the relative scale of exports of toys from China by importing market, illustrating the increasing interdependence and global

**Figure 4.2** **Relative scale of exports of toys from China by importing market (based on Atlas 2018)**



character of current supply chains. In 2017 China imported more than US dollars 61 billion worth of plastic materials, some of which were used in the manufacture of toys. In the same year it exported approximately US dollars 43.7 billion worth of toys.

The automotive industry is another example. Divestment of large portions of the automotive supply chain has occurred, including outsourcing of cost- and labour-intensive manufacturing portions as semi-independent or wholly independent units (Bitran *et al.* 2006). Such disintegration leads to a more complex, but also more flexible, automotive supply chain network. As a result, the level of interaction and coordination between actors involved in the supply chain increases significantly even if the number of supply chain layers, from components to finished products, remains the same.

## Supply chains are fragmented and complex

Global production and supply chain systems span the globe, creating value across entire production and product systems and product life cycles, industries and consumers. The global supply chain of each sector includes various networks around the world for raw materials extraction; production and processing of intermediate goods and materials; final products manufacturing; export and distribution; and marketing of the final products. A generalized global supply chain for the textile sector is presented in Figure 4.3. Some of these networks have introduced innovative management action, such as a sector-specific restricted substance list (Apparel and Footwear International RSL Management Group 2018). (Further examples are provided in Part III, Ch. 4 and Part IV, Ch. 7.)

**Figure 4.3** Global supply chain in the textile sector (adapted from Martin 2013, p. 6)

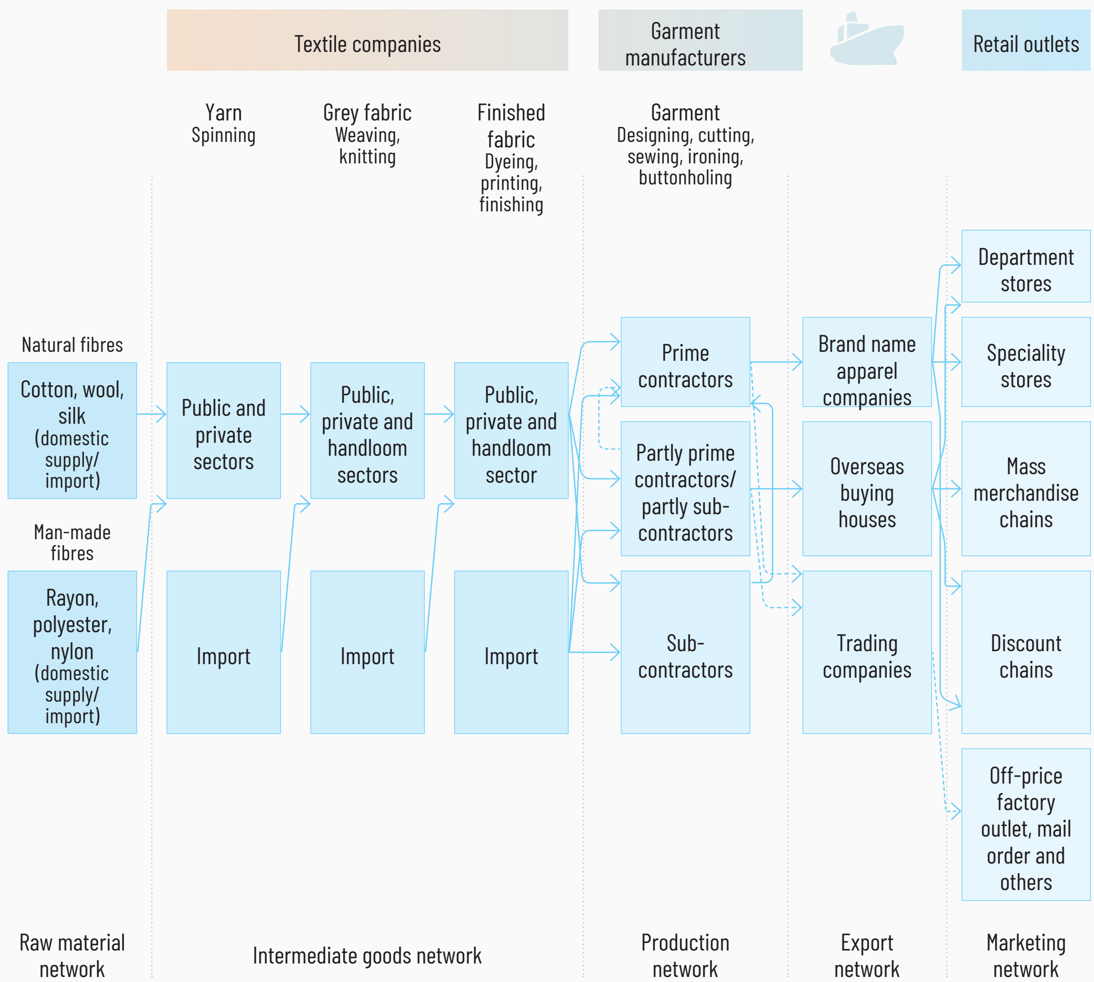


**Table 4.1** Actors, main impact drivers and exposure over the product life cycle of toys

| Life cycle stage | Actors | Main impact drivers and exposures | Evaluation tools and challenges | Management tools and entry point |
|---|---|---|---|---|
| Oil extraction and refinery | Oil companies | Worker exposures and industrial releases | Life cycle inventory of raw materials and oil refinery processes | |
| Chemical and plastic manufacturing | Chemical and plastic manufacturers | Worker exposures and industrial releases | Environmental genome of industrial products (EGIP) (Overcash 2016) | Supply chain management (SCM) |
| Toy design, manufacturing, assembling | Original equipment Manufacturers, market surveillance enforcement authorities | Product design worker exposure and industrial releases | Design for Environment worker exposure assessment (Kijko, Jolliet and Margni 2016) | SCM, ensure traceability of products, components |
| Trade – distribution, retail | Retailers, traders, enforcement authorities testing organizations | Transportation | Disclosure of product composition | Retailer disclosure policy labels |
| Purchase and use | Consumers, NGOs | Near-field exposures to chemicals in products, energy usage | Product Intake Fraction modeling (Fantke *et al.* 2016) | |
| Recycling | Recyclers – both formal and informal sectors | Chemical residues and contamination of recycled material | Material flow analysis, life cycle assessments (LCAs) | Dismantling as focus for informal sector, recycling and waste treatment for formal sector |
| Waste management | Municipalities, waste treatment facilities, recycling facilities, etc. | Waste treatment releases | End-of-life LCAs | From waste management to resource management |

Traditional hierarchical and one-dimensional supply chains have largely been transformed into fragmented networks, involving strategic partnerships between many companies located in different parts of the world.

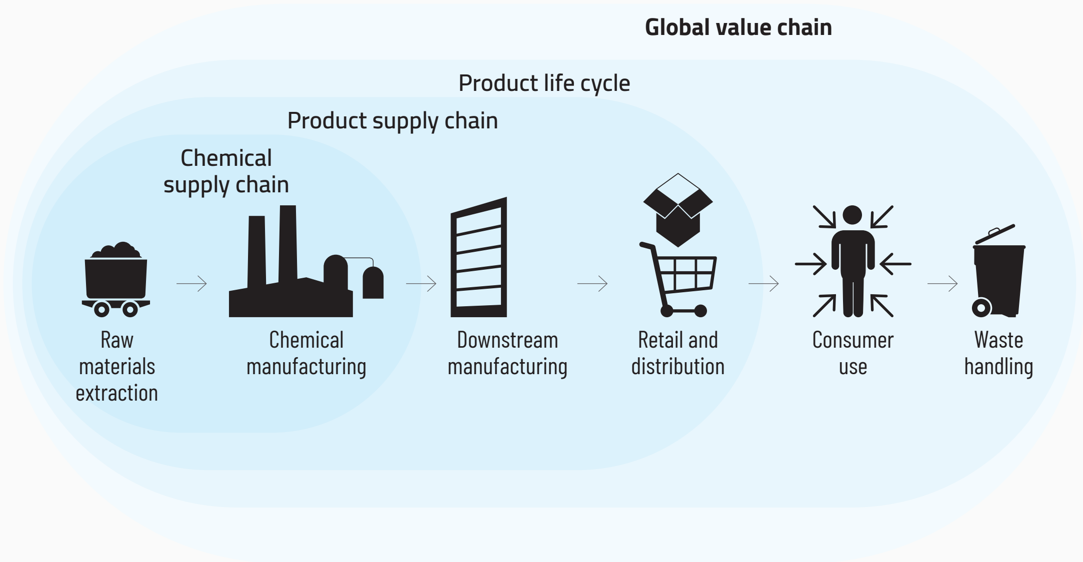
### Different commodities involve different key players

The complexity of global supply chains implies that multiple stakeholders are involved, including resource extractors, chemical manufacturers, product manufacturers, bystanders, retailers, consumers, civil society organizations, and governments and international regulators. Table 4.1 shows key actors, drivers of chemicals-related impacts, evaluation tools and challenges, and indicative management options for each life cycle stage of toys. The institutional framework established on the international and national levels must be designed in a way that adequately responds to this complexity (responsive regulation), while the governance mechanisms at company level must address the complexity of its (global) supply chains.

## 4.2 Understanding chemicals in products and product life cycles

Manufactured chemicals are constituents of materials and products that we encounter in daily life. The global value chain of chemicals and products has several stages: raw materials are extracted and synthesized into chemicals, polymers and materials; products are manufactured and distributed; and, following consumption, products enter recycling or become waste. The life cycles of chemicals and of products are therefore closely interconnected. Each chemical has its own life cycle, from resource extraction, to chemical synthesis, to incorporation into a chemical formulation, composite material or product, to product use, to end-of-life treatment. Products, in turn, have their own resource extraction, product manufacturing

**Figure 4.4** **Relationship between global value chains, product life cycles, product supply chains and chemical supply chains in a linear economy**




Supply chains are concerned with the flow (and purchase) of materials from the point of origin (e.g. raw material) to the point of use (product). The product life cycle extends from raw material extraction to waste handling. The global value chain concept refers to the broader system of adding value to an article (e.g. through production, marketing, and after-sales service and product stewardship).

or end-of-life treatment processes. Emissions of, and exposure to, chemicals may occur throughout all stages of the chemical and product supply chains and product life cycle. Figure 4.4 illustrates the relationship between global value chains, product life cycles, product supply chains and chemical supply chains in a linear economy.

## Use and functions of chemicals along the product life cycle

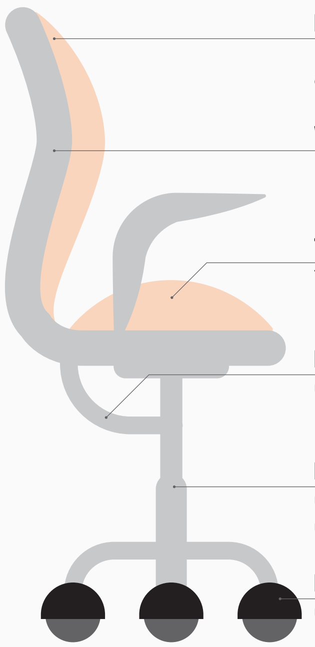
Chemicals fulfil diverse specific functions, as basic constituents of simple and composite materials and polymers (e.g. as stabilizers or adhesives) and to shape the quality of end market products (e.g. colour, viscosity, stability). Furthermore, they fulfil specific functions in the realm of production and product systems within the product life cycle. For example, chemicals are used in auxiliary processes for resource extraction (e.g. potassium chloride to recover crude oil from shale rock), in manufacturing (e.g. hydrogen peroxide in pulp and paper bleaching), during product use (e.g. hydrofluorocarbon refrigerants to run air conditioners) and in waste treatment (e.g. sodium hydroxide to remove paint from disposed products).

Most chemicals are synthesized and manufactured in complex production systems. During this process, some chemicals are used as processing input (e.g. catalyst) while others are generated as intentional co-products or unintentional by-products (Overcash 2016). Unintentional chemical by-products may include persistent, bioaccumulative and toxic compounds, such as dioxins formed as the result of incomplete combustion (Baker and Hites 2000) or during the manufacturing of chlorinated pesticides (Holt *et al.* 2010). In contrast, chemical co-products are subsequently used, for example, as solvents in specialty chemicals. An example is the production of polyethylene from crude oil, which also yields, among others, benzene as chemical co-product.

## The chemical content in products varies

Modern-day products often contain hundreds of chemicals (Figure 4.5). Many of these chemicals

**Figure 4.5** **Chemicals in an office chair (adapted from Swedish Chemicals Agency [KEMI] 2016a, p. 7)**




may have hazardous properties. The universe of products includes formulated chemical products (often sold as liquids, gels or aerosols with certain performance properties) as well as articles (products whose function is determined primarily by shape rather than by a particular chemical composition). Examples of chemicals in products include formaldehyde in shampoo, microbeads in toothpaste, phthalates in food packaging, certain flame retardants in televisions, and antimicrobials (e.g. triclosan) in soaps. Many formulated products (e.g. personal care products and household cleaners) contain multiple chemical compounds of distinct composition (as a function of brand, regulatory requirements and target consumers), yet fulfil the same desired function.

In a number of cases simple metal or wooden tools, toys and household products have been replaced by products made of complex polymer and composite materials filled with a wide range of functional additives. Some of the intentionally added chemicals in today's complex composite materials may have hazardous properties. For example, in 2013 in the State of Washington in the United States companies were required to disclose the use of chemicals of high concern (e.g. cadmium, mercury, molybdenum, antimony and cobalt) if they were present in children's products that were sold (Uding and Schreder 2013). In the United States textiles, skin products, plastics and other children's items have been found to contain potentially hormone-disrupting chemicals such as certain phthalates, bisphenol A, parabens, nonylphenol and D4; low levels of phthalates have been found in more than 700 products (Kay 2013).

Concentrations of chemicals in products vary widely, depending on the intended function (Isaacs *et al.* 2018), with some formulated products containing chemicals of concern at significant concentrations. For certain classes of products, such as cleaning products, the chemical composition and content have been relatively well-characterized. They are available through different databases (e.g. Goldsmith *et al.* 2014) or can be estimated based on the chemical function (Phillips *et al.* 2017). Concentrations range, for example, from up to 50 per cent in plasticizers or flame retardants to less than 0.01 per cent in pigments or some solvents (Hansen, Nilsson and Ravnholt Vium 2014). Solvents in body lotion account for approximately 60 per cent of mass/volume (Figure 4.6, left side), while colourants account for approximately 0.5 per cent.

However, for many products, such as building materials, the chemical composition is often unknown. This creates challenges for assessing associated exposure and risks. At present,

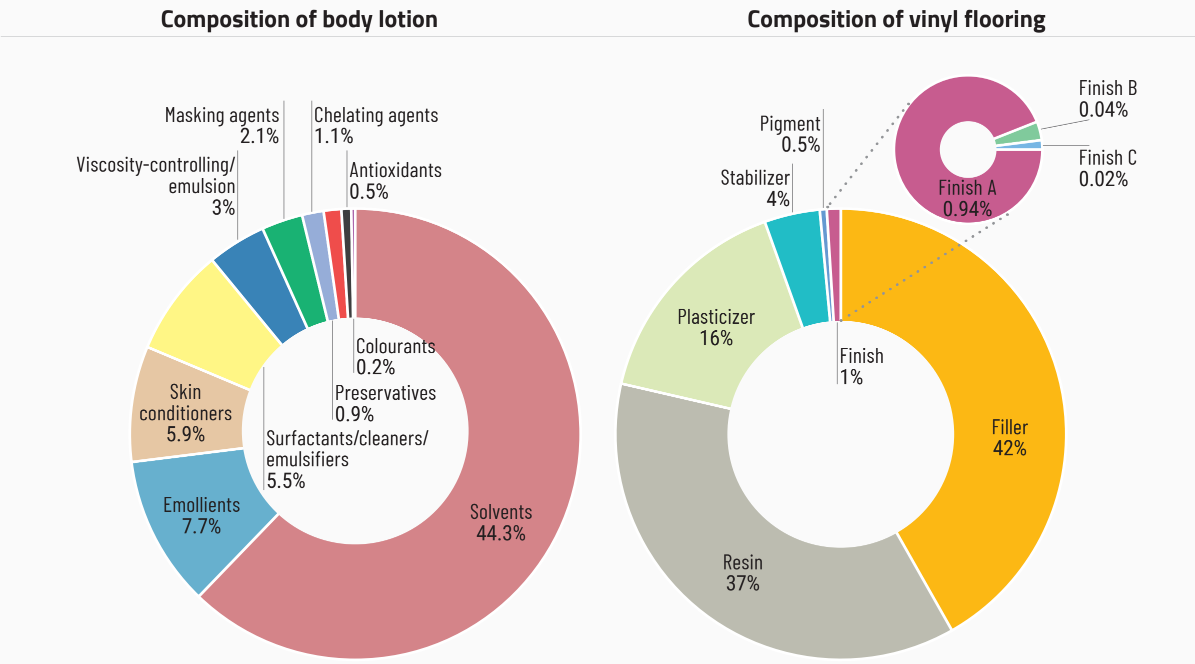

© Africa Studio/Shutterstock

Various unintended chemical contaminants have been found in rubber on playgrounds and football fields.

assessments of such products rely on databases derived from product safety datasheets (e.g. for vinyl flooring) (Figure 4.6, right side) and current composition industry databases (e.g. the Pharos database developed by the Healthy Building Network).

In some cases, products may contain chemicals despite the existence of regulations that limit or prohibit their use. Several such cases have been reported in recent years. For example, the Swedish Chemicals Agency analyzed a number of electrical and electronic products

**Figure 4.6** **Variations in chemical content in a body lotion and in vinyl flooring (per cent) (adapted from Fantke *et al.* 2019 and Isaacs *et al.* 2016, p. 728)**



and found 38 per cent to contain too high levels of prohibited chemical substances, including lead and short chain chlorinated paraffins (KEMI 2016b).

### Unintentional chemical residues show up in articles and products

In addition to intentionally added chemicals that fulfil a certain performance function, products and their articles may also contain unintended chemical contaminants. These chemicals may be residuals from the chemicals used in product manufacture, or may originate from packaging or other sources such as cross-contamination via recycling. Moreover, chemicals included in pharmaceuticals, pesticide formulations or plastics may become residues in other products such as food products (Fantke, Friedrich and Jolliet 2012). Food contaminants typically include environmental contaminants, food processing contaminants, unapproved adulterants and food additives, and chemical migrants from packaging materials. If they are characterized by a high fat content, food products are likely to absorb chemicals from plastic packaging and other materials. Some persistent environmental contaminants tend to accumulate in meat, poultry, fish and dairy products. Other chemicals, such as perchlorate and pesticides, are present in fruits, vegetables and other agricultural commodities at various concentrations. This is further explored in Part I, Ch. 6.

Table 4.2 provides some specific examples of studies which have identified residues of unintentional chemicals in products. Unintended chemical residues are usually found at trace

**Table 4.2 Examples of studies identifying unintended chemical contaminants in products**

| Product/article | Chemical(s) | Example study |
|---|---|---|
| Thermo cups and kitchen utensils | brominated flame retardants, e.g. decabromodiphenyl ether (decaBDE), tetrabromobisphenol A (TBBPA) | Samsonek and Puype 2013 |
| Electrical articles | lead | KEMI 2014 |
| Waste paper and board from households | mineral oil hydrocarbons, phthalates, phenols, polychlorinated biphenyls, and selected toxic metals | Pivnenko *et al.* 2016 |
| Children's toys | polybrominated diphenyl ethers (PBDEs) and phosphate flame retardants (PFRs); plasticizers such as phthalate esters | Ionas *et al.* 2014 |
| Packaging material | hexabromocyclododecane (HBCDD) | Bodar *et al.* 2018 |
| Rubber on playgrounds and football fields | polycyclic aromatic hydrocarbons (PAHs), phthalates, antioxidants (e.g. BHT, phenols), benzothiazole and derivatives | Llompart *et al.* 2013, Bodar *et al.* 2018 |
| Pizza board package | phthalates and synthetic biocides | Pieke, Smedsgaard and Granby 2018 |
| Various food samples | bisphenols | Liao and Kannan 2013 |
| Commercial salt | microplastics (polypropylene, polyethylene and others) | Karami *et al.* 2017 |
| Honey | neonicotinoids (acetamiprid, clothianidin, imidacloprid, thiacloprid and thiamethoxam) | Mitchell *et al.* 2017 |
| Lettuce | various pesticides | Skovgaard *et al.* 2017 |
| Various food samples | DDE (a DDT metabolite), PCB congeners, PFOA and others | Schecter *et al.* 2010 |
| Wine | lead (584 µg/kg, sample taken in 2015) | WHO 2018 |
| Cooked crabs | dioxins (WHO TEF; 740 pg/kg; sample taken in 2010 | WHO 2018 |

Whether the presence of chemical contaminants in products poses a risk depends on exposure and is determined by a number of factors, as further explored in Part III. This overview does not provide an assessment of whether measured concentrations exceeded relevant thresholds set by regulatory bodies (further information is provided in Part I, Ch. 6).

levels and at the lower end of the range of content fractions compared to intentional chemical ingredients, unless there is mishandling or an accident in chemical formulation. Yet they may create challenges for recycling and for ensuring that material cycles are non-toxic.

## Chemicals, waste and circularity

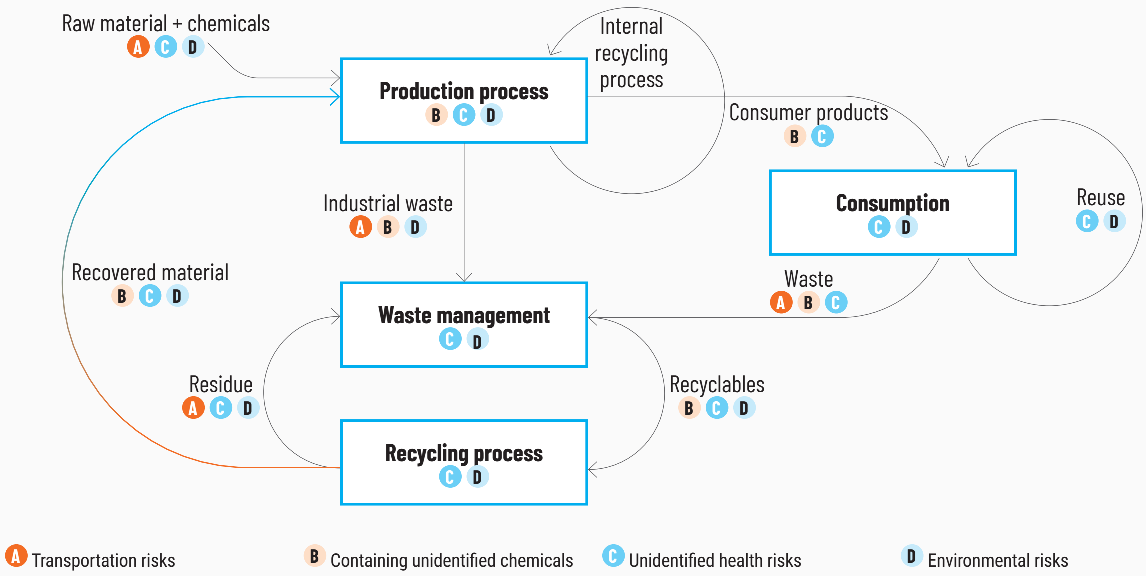
The circular economy concept seeks to minimize the extraction of natural resources, keep the extracted resources in use as long as possible, and promote recovery and regeneration of products and materials at the end of their life cycles. Such reuse and recycling is compatible with international policy objectives that aim at promoting environmental sustainability and resource efficiency (Bodar *et al.* 2018). Despite some differences in interpretation, the circular economy concept has recently been gaining attention in the scientific and policy communities (Homrich *et al.* 2018) as well as the private sector (Accenture 2017).

The increasing trade of chemicals and related products, and the quest to recycle products and materials, create opportunities but also raise concerns regarding the fate of chemicals and chemicals in products once they reach the waste stage or become secondary raw materials. Challenges include the chemical content of products becoming secondary raw materials, as well as the global flows of recycled products often being unknown, potentially impeding management intervention that could ensure undesired chemicals re-entering supply chains are not causing health and safety problems at various stages of the material flow (Figure 4.7).

As various products such as paper and cardboard, plastics and lubricants are recycled, they may become “secondary raw materials”. Products made from recycled materials (e.g. textiles and carpets) may contain, for example, heavy metal traces from the original product applications. Studies have found, among others, flame retardants in consumer products most likely originating from recycled plastics (Schecter *et al.* 2011) and various chemical contaminants in recyclable waste paper derived from households (Figure 4.8) Another study (Llompart *et al.* 2013) found various hazardous substances in rubber playground equipment, including high concentrations of polycyclic aromatic hydrocarbons (PAHs) likely originating from recycled rubber tyres. Furthermore, there is mounting evidence that the demand for black plastics in consumer products is partly met by sourcing materials from the plastic housings of end-of-life waste electronic and electrical equipment. This creates a potential to introduce restricted and hazardous substances into the recyclate (e.g. including brominated flame retardants; antimony, a flame retardant synergist;

Various chemical contaminants have been found in recyclable waste paper.

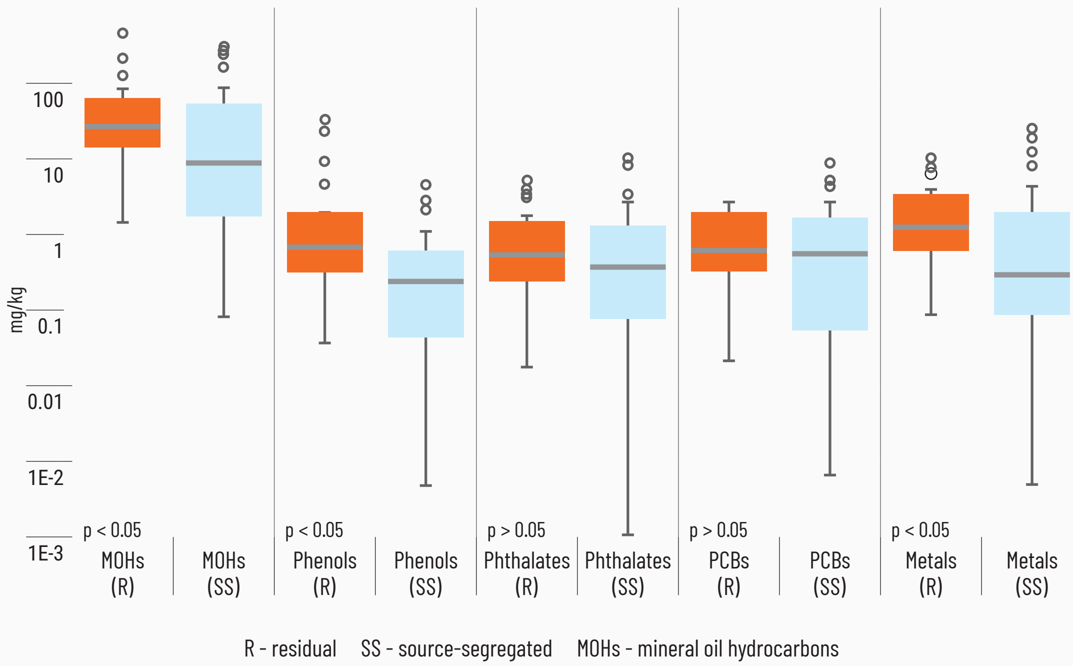
**Figure 4.7** Simplified material flow of a circular economy in a global scale with health and environmental risks (adapted from Grundmann *et al.* 2013, p. 2)




and the heavy metals cadmium, chromium, mercury and lead) (Turner 2018).

The presence of hazardous substances in products, whether intentional or unintentional, including through recycling, thus poses challenges

**Figure 4.8** Unintended residues found in recyclable waste paper (mg/kg) (adapted from Pivnenko *et al.* 2016, p. 51)




Reprinted with permission from Elsevier.

The values for PCBs are in µg/kg. The p values indicate a significant ($p < 0.05$) or non-significant ($p > 0.05$) difference between residual and source-segregated waste paper.

to circularity and the implementation of the waste hierarchy, which emphasizes source reduction, reuse and recycling. A coherent approach to the sound management of chemicals and waste in a circularity context implies that undesired substances are not used in consumer products, and that potential cross-contamination and related exposures or releases to the environment are avoided. A challenge for all actors engaged in the supply chain is therefore to effectively address potential trade-offs between increasing recycling rates on the one hand, and consumer and environmental exposure associated with cross-contaminated products on the other. At the same time, these considerations create a driver and opportunity for the chemical and engineering sciences to provide the basis for innovative products that can be reused and recycled without sustainability trade-offs. Under this paradigm, substances and chemicals in products are considered as a resource and not as potential wastes (Clark *et al.* 2016).

Further gaps and research needs closely related to achieving the sound management of chemicals and waste throughout the life cycle include the following (Grundmann *et al.* 2013):

- lack of data about chemicals in products;
- risks of chemical mixtures;
- releases of chemicals from materials and goods;
- scarce information on characteristics related to use of chemicals;
- associated uncertainty missing for *in vivo* experiments;
- the need to increase the acceptability of alternative methods;
- lack of information and missing common databases for additives;
- limited specific data about informal recycling processes (e.g. efficiency, emissions);
- lack of more detailed emission models for products; and
- lack of a clear link between emissions and impacts of chemicals.

## 4.3 Sustainability considerations across chemical supply chains and product life cycles

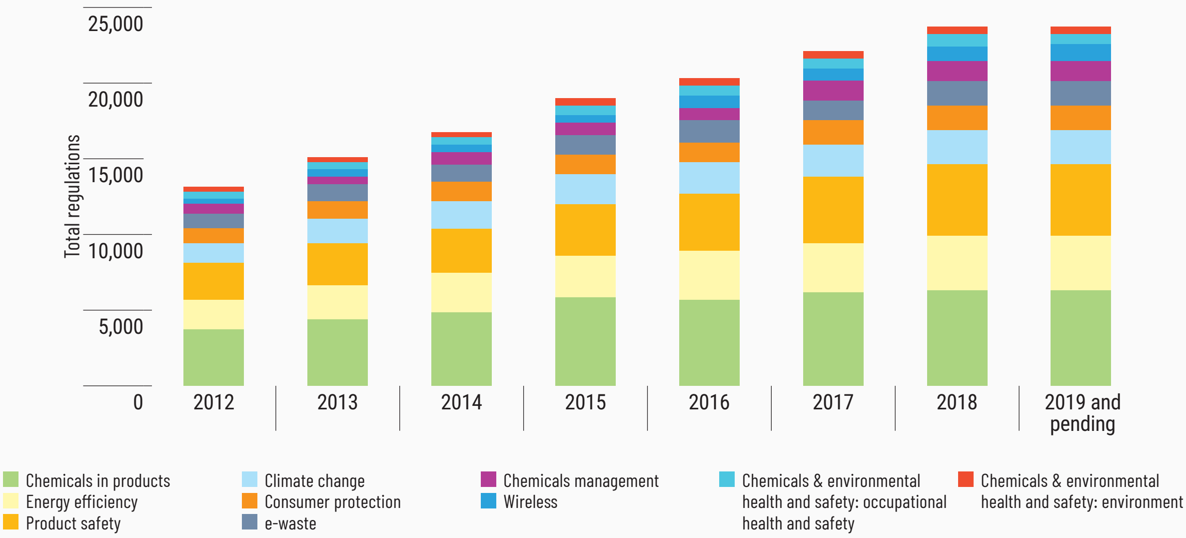
### Management challenges across complex supply chains

Global supply chains within and across industry sectors, along with the increasing global trade of goods, have created challenges from a sustainability perspective. These challenges

**Box 4.1 An example of challenges related to the interface of chemicals, waste and circularity: the phthalate plasticizer DEHP in PVC (adapted from EC 2018)**

Flexible PVC from post-consumer waste can contain up to 20 per cent of the plasticizer substance DEHP. This plasticizer is classified as hazardous due to its adverse effects on the human reproductive system and is subject to certain use restrictions and to authorization in the EU. When PVC containing DEHP is recovered, it is subject to authorization under the EU's Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) Regulation and must comply with the REACH and Classification, Labelling and Packaging (CLP) rules for hazardous mixtures in order to reach end-of-waste status. There are, however, no EU harmonized or national end-of-waste criteria applicable to PVC waste containing DEHP and no relevant national case-by-case decisions. Yet a number of recycling companies have applied for authorization to use the recycled material under REACH, considering their PVC containing DEHP no longer to be in the waste phase. Lack of harmonization and different interpretations of waste classification and end-of-waste provisions have led to uncertainties about the conditions under which operators must continue to manage and trade this material as waste rather than as a product.

**Figure 4.9** Concept-to-production (C2P) global regulations by subject, cumulative total (adapted from Compliance and Risks 2018)




include unintended releases of chemicals during resource extraction and manufacturing; occupational exposures during manufacturing; consumer exposures during use; and releases during recycling or disposal at the end of a product's useful life. Many of the companies involved (sometimes SMEs) operate in countries with limited regulatory capacity. In addition, international trade may shift problems from one region to another (Wiedmann and Lenzen 2018).

In complex global supply chains it may be difficult for final product brand-identified corporations, such as Apple, Nike, Adidas, Unilever, Ford and Volkswagen, to manage their suppliers. One challenge is to know what chemicals are in the components or articles that go into the products that they bring onto the market. For example, the lead paint discovered in 2007 on the toy trains Mattel marketed worldwide appear to have been the result of undisclosed activities of second and third tier suppliers in the supply chain (Jennings 2007). The same applies to environmental emissions associated with the different extraction, manufacturing and processing steps along the entire supply chain of a product.

### Managing complex supply chains: policy instruments and challenges

The number of standards and regulations to manage global supply chains and extended producer responsibility has increased significantly over the last 15 years (Figure 4.9). These include, but are not limited to, regulations addressing production processes, individual substances and harmful product constituents, product safety measures and waste handling. However, while codes, standards and regulations are mostly national, supply chains are global, complicating effective management. This situation, and the increasing global trade of chemicals and products (described in Part I, Ch. 1, 2), create opportunities to explore approaches for effective global governance that can reduce impacts along the entire supply chain. This includes measures to avoid burden shifting (i.e. avoiding adverse impacts associated with imported goods in the exporting manufacturing countries) (Normile 2017), or avoiding waste from exporting countries creating adverse impacts in importing countries. Agreements that facilitate trade therefore need to foster effective regulations that take into account human health and environmental considerations related to chemicals and waste across countries.

One growing challenge to ensuring compliance with regulatory requirements in different parts of the world, and for complex supply chains, relates to cross-border trade and e-commerce. Recent research shows that imported chemicals or products often do not comply with the chemicals legislation of the importing country (see also Part II, Ch. 3). For example, various products imported into the EU were found to contain illegal amounts of restricted chemicals (ECHA 2018a). Similar challenges have been encountered in the United States. For example, 12 per cent of imported shrimp tested for drug residue and other toxins were rejected (US Government Accountability Office 2017).

As regards e-commerce, many chemicals can now be ordered directly from anywhere in the world by private entities which may be unaware of safety regulations and responsibilities. In 2017 the ECHA conducted an inspection of 1,314 internet advertisements for chemical mixtures to determine whether they complied with EU CLP regulations. It found that 82 per cent did not contain the required hazard information. Most of the advertised chemical mixtures were used in households (37 per cent), were used in construction (16 per cent) or were motor products (14 per cent) (ECHA 2018b).

The trend towards circularity also creates challenges for aligning chemicals and waste standards and regulations. In a non-circular economy, products usually become waste and thus fall under the respective waste legislations. However, in a circular economy recyclable materials and products increasingly become "secondary raw materials" to which different regulatory requirements apply, such as specific end-of-waste criteria. The challenge is to ensure that hazardous materials do not re-enter the life cycle in new materials as a result of a circular approach. In Europe end-of-waste criteria have already been specifically developed for iron, steel and aluminium scrap, glass cullet and copper scrap. Opportunities exist to develop such criteria for a wider realm of recyclable materials and products, such as waste plastic re-entering the market (Villanueva and Eder 2014).

## Assessing impacts across supply chains and product life cycles

Addressing chemical and product life cycles in a sustainable way requires proper management of information flows and feedback loops among stakeholders involved in the supply chain. Approaches are emerging which complement market-based supply chain management, measuring the environmental as well as social impacts associated with chemical pollution and working conditions along the supply chain and throughout the life cycle. Measuring environmental and social sustainability upstream and downstream can provide a basis for increasing full supply-chain sustainability (O'Rourke 2014). Advances in life cycle assessment (LCA) and in the calculation of product environmental footprints may help translate impacts into decision support for companies (Hellweg and Milà i Canals 2014). However, LCA is not without its own limitations, challenges and critiques; it should therefore be applied and interpreted with caution (Gutowski 2018). Opportunities also exist to advance the integration of the chemicals dimension in LCA models and tools. Further details are provided in Part III, Ch. 7.

Life cycle management (LCM) encourages a holistic perspective. It covers the entire chemical or product life cycle and calls for managerial decisions that consider environmental and health impacts. LCM provides an opportunity to minimize the environmental and socio-economic burden while maximizing economic and social value (Bey 2018). Applying the life cycle perspective is also of key relevance in advancing a circular economy and closing material loops along chemical and product life cycles and creating self-sustaining production systems. A holistic view in assessing chemical-related releases to the environment, or human exposure, helps identify and avoid performance improvements at one life cycle stage (e.g. decreased raw material extraction through recycling) at the expense of increased impacts at another stage (e.g. increased residues of contaminants in recirculates and related consumer exposure and related human health risks). It helps avoid what is commonly known as burden-shifting (Hellweg and Milà i Canals 2014). Finally, assessing and managing chemicals along entire product life cycles allows environmental performance of products, and their supply chains, to be benchmarked against pollution and exposure reduction targets set by the global sustainable development agenda in support of developing products and technologies that are sustainable in absolute terms (Fantke and Illner 2019).

### Enhancing traceability of chemicals in the supply chain

Ensuring the traceability of chemicals along the supply chain has been addressed by the Strategic Approach to International Chemicals Management (SAICM) for many years, and was added in 2015 to the International Organization for Standardization (ISO) 9000 series on quality management and quality assurance management series. It is a key feature to address product stewardship along the supply chain. In this respect, the "Proactive Alliance" is developing criteria for a cross-sectoral global standard heading towards a "Full Material Disclosure" (FMD) as a governance response to the complexity and various interlinks of the global supply chain. Regulatory approaches aiming to support a circular economy, such as the substances of very high concern (SVHC) database to be hosted by the ECHA, have been triggering this development (Global inter-sector standard for Substances in Articles [SiA] communication 2018; Stringer 2018).

# 5/ Chemical pollution: emissions, releases and wastes

## Chapter Highlights

Large amounts of manufactured chemicals continue to be released to the air, water and soil.

Releases of heavy metals continue to pollute soils worldwide.

Total fertilizer and pesticide applications to soil are increasing, but application rates are decreasing.

Globally, atmospheric releases of mercury remain high.

Chemicals of concern are released indoors from consumer products and building materials.

Significant progress has been made in reducing releases of some chemicals of concern, including ozone-depleting substances and some persistent organic pollutants (POPs).

Waste dumps and informal recycling are major sources of pollution in many countries.

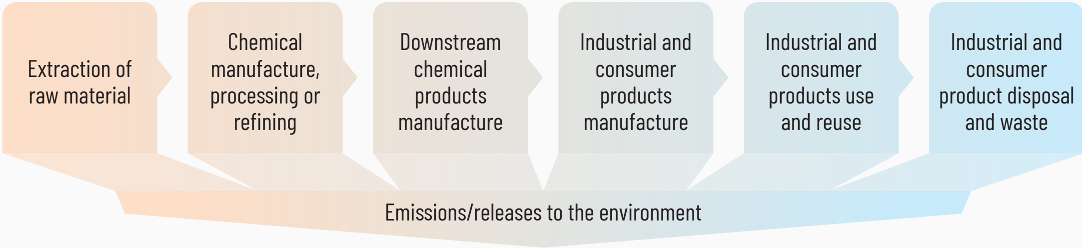
Industrial accidents and natural disasters result in significant pollution.

This chapter compiles and synthesizes available information on the emissions and releases of chemicals to indoor and outdoor environments and on the generation of waste, particularly hazardous waste. Since chemicals are released to various media and released from various sources, both the media and the sources are considered. The first part of the chapter addresses the environmental media as an entry point, using knowledge on releases to air, freshwater and oceans, and soil. The second part takes the source categories as an entry point, exploring releases from products, production processes, municipal and hazardous waste, and industrial accidents and natural disasters. The chapter concludes with a brief discussion of challenges and opportunities in regard to compiling pertinent data and knowledge.

## Emissions to air, water and soil

Every year millions of tonnes of manufactured chemicals are released to the environment as air emissions, water discharges, and solid and hazardous waste. While simulation models can be used to estimate the scale of the releases, an accurate assessment of their volumes is inhibited by the multitude of sources. Traces of these emissions and releases are found as pollutants in environmental media in every world region. In many parts of the world emissions and releases of many hazardous chemicals are increasing. Not only do these emissions pose risks to human health and the environment. They also represent lost opportunities to realize economic benefits.

**Figure 5.1** The value chain of the chemical industry, with emissions/releases to the environment




Manufactured chemicals can be released at each step in the value chain of the global chemicals economy (Figure 5.1). Large volumes occur as waste materials generated by specific technologies and economic processes. Significant amounts are also released as unintentional leaks, spills and fugitive emissions.

Some of the largest sources of releases of hazardous chemicals are mining, agriculture, wastewater treatment, energy generation, chemical production, and product manufacturing, use and disposal. There is no comprehensive global system for monitoring and tracking these releases. While ambient air measurement and modelling can provide important insights, they cannot replace production or release inventories. Some 30 countries have established national Pollutant Release and Transfer Registers (PRTRs) to track releases of hazardous chemicals from industrial facilities (OECD 2018). PRTRs are useful for monitoring national emissions. However, their usefulness for aggregating data and assessing global trends is restricted by the limited number of chemicals and diverse types of facilities covered, as well as varying reporting thresholds and periods (US EPA n.d. a) (see also Part II, Ch. 3).

## 5.1.1 Emissions to air

Manufactured chemicals enter the atmosphere through direct emissions, including from stationary point and area sources such as factories and parking lots; mobile sources such as cars and airplanes; diffuse emissions, including pesticide spraying; and fugitive emissions such as those from commercial and household products. Because air emissions travel long distances and have impacts on countries outside the country

of their origin, air pollution is a significant transboundary issue.

## Releases of ozone-depleting substances have been sharply reduced

National policies established in conformance with the Montreal Protocol on Substances that Deplete the Ozone Layer, which entered into force in 1989 (see Part II, Ch. 1-3), have led to the phase-out of 99 per cent of ozone-depleting chemicals, resulting in significant reductions in releases (Secretariat of the Vienna Convention and its Montreal Protocol 2018). The remaining 1 per cent consists largely of hydrochlorofluorocarbons (HCFCs), a group of controlled substances with ozone-depleting potential much lower than that of the ozone-depleting substances (ODS) they replace (e.g. chlorofluorocarbons [CFCs] and halons). In 2009 it was estimated that this reduction had contributed to climate change mitigation through averting the emission of 135 billion tonnes of carbon dioxide equivalent ($CO_2$-eq) to the atmosphere (Molina *et al.* 2009).

In 2007 the Parties to the Montreal Protocol decided to accelerate the phase-out of HCFCs. In 2016 they agreed to phase down the consumption and production of hydrofluorocarbons (HFCs), as stipulated in the Kigali Amendment to the Montreal Protocol (UNEP 2016a). While HFCs are not ODS, they are powerful GHGs that are used as ODS substitutes primarily in air conditioning, refrigeration and foam insulation. HFCs can be thousands of times more harmful to the climate than $CO_2$. In 2010, however, 5.4 million tonnes of ODS were estimated to be banked in existing refrigeration and air conditioning equipment, and contained in insulation foam, that could gradually be vented into the atmosphere (UNEP 2009).

A recent study published in *Nature* (Montzka *et al.* 2018) indicated that trichlorofluoromethane (CFC-11) still contributes one-quarter of all chlorine reaching the stratosphere, while a timely recovery of the stratospheric ozone layer depends on a sustained decline in CFC-11 concentrations. The rate of decline of atmospheric CFC-11 concentrations observed at remote measurement sites was constant from 2002 to 2012. It slowed by about 50 per cent after 2012. Based on a simple model analysis, an increase in CFC-11 emissions of 13 ± 5 gigagrams per year since 2012 has been suggested, despite reported production being close to zero since 2006. According to the study, the increase in emissions of CFC-11 appears unrelated to past production, suggesting unreported new production. Further research on this matter is being undertaken. However, the recent discovery of the rate of decline of CFC-11 in the atmosphere, and the potential increase in emissions, demonstrate the importance of continued atmospheric monitoring even when global compliance is high.

## The chemical industry is a significant source of greenhouse gas emissions

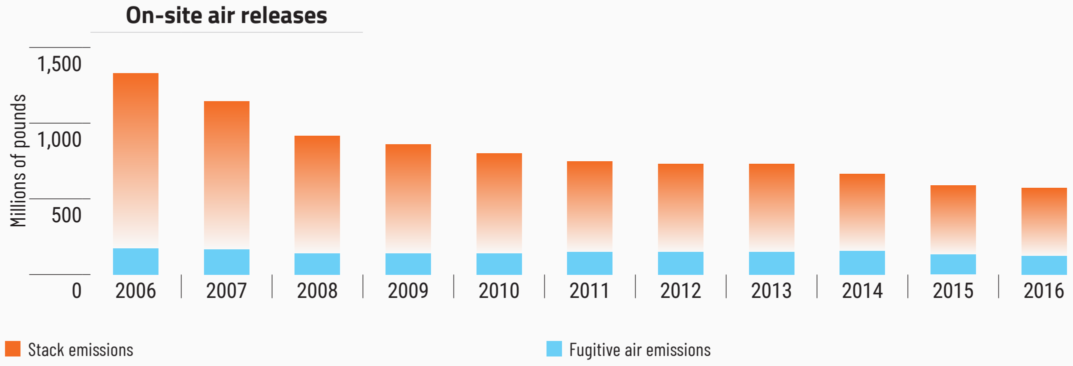
The chemical industry generates about 5.5 per cent of global $CO_2$ emissions (7 per cent of global GHG emissions) and about 17 per cent of all industrial $CO_2$ emissions (20 per cent of all industrial GHG emissions). During the past decade it has made significant reductions in its energy consumption and GHG emissions, a trend which is expected to continue (IEA, ICCA and Society for Chemical Engineering and Biotechnology 2013).

Some of the chemicals manufactured by the chemical industry also contribute to GHG emissions. Use of nitrogen-based fertilizers in agriculture (which rose from 11 million tonnes in 1961 to 108 million tonnes in 2014) contributes substantially to emissions of nitrous oxide, an extremely potent GHG. Sulphur hexafluoride, another extremely potent GHG, continues to be used in (and released from) the electronic product manufacturing and magnesium industries, while fluorinated ethers used in degreasing applications are emitted directly to the atmosphere (EEA 2017a).

## Releases of hazardous air pollutants vary by region

In middle- and higher-income countries governments monitor and regulate national "priority air pollutants" (e.g. particulate matter, ground level ozone, carbon monoxide, lead,

**Figure 5.2** On-site air releases in the United States reported to the Toxics Release Inventory (TRI), 2006-2016 (million pounds) (adapted from US EPA 2019, p. 39)




and sulphur and nitrogen oxides) that are largely generated by combustion. There has been a general long-term decline in releases of these chemicals except in the case of lead, whose emission rates vary between countries (EEA 2017b; US EPA n.d. b). However, emissions of these same chemicals are increasing in the rapidly urbanizing cities of many emerging economies, often leading to highly polluted urban air.

Atmospheric releases of manufactured chemicals from industrial sources are tracked by national PRTRs (see above). Those chemicals with the largest volume releases to air reported under the United States Toxics Release Inventory (TRI) (the PRTR in the United States) include ammonia, hydrochloric acid, methane, sulphuric acid and hydrogen sulphide, along with organic chemicals such as methane, n-hexane, styrene and toluene. Between 2006 and 2016 releases of these chemicals to air decreased by 58 per cent (829 million pounds); the most significant reductions were of hydrochloric acid, sulphuric acid, hydrogen fluoride, methanol, toluene and styrene (US EPA 2019). Figure 5.2 shows trends for hazardous chemicals released to the atmosphere by regulated facilities, as reported to the TRI.

The European Environment Agency (EEA) PRTR has reported that emissions of nitrous oxide, sulphur dioxide and ammonia decreased significantly in most European countries between 1990 and 2012 (EEA 2015). Emissions of industrial air pollutants such as heavy metals and volatile organic compounds (VOCs) also declined, while emissions of lead, cadmium and mercury, dioxins and furans, hexachlorobenzene and PCBs decreased by 67 per cent or more compared with 1990 (Guerreiro *et al.* 2015). Around 94 per cent of air emissions of ammonia in Europe are from agriculture. According to a recent EEA report, these emissions decreased by 23 per cent between 1990 and 2015 but increased between 2014 and 2015 by 1.8 per cent, with much of that increase occurring in France, Germany and Spain (EEA 2017b).

The extent of atmospheric releases of manufactured chemicals from industrial sources in lower-income countries is difficult to determine in the absence of national monitoring systems, such as national PRTRs, in many of these countries.

## Emissions of some POPs have decreased but those of others continue

Atmospheric emissions of various POPs have decreased significantly since 1990 among Parties to the Convention on Long-range Transboundary Air Pollution (e.g. 95 per cent for hexachlorobenzene, 75 per cent for PCBs, 70 per cent for dioxins and furans and 83 per cent for PAHs) (EEA 2018). A review of monitoring data from the Arctic Monitoring and Assessment Programme (AMAP) collected over 20 years reveals that primary emissions of most of the POPs first listed under the Stockholm Convention


are declining. Trends are less positive for other POPs, notably polybromated diphenyl ethers (PBDEs), HCB and PCBs, among others, due in part to their remobilization (Hung *et al.* 2016).

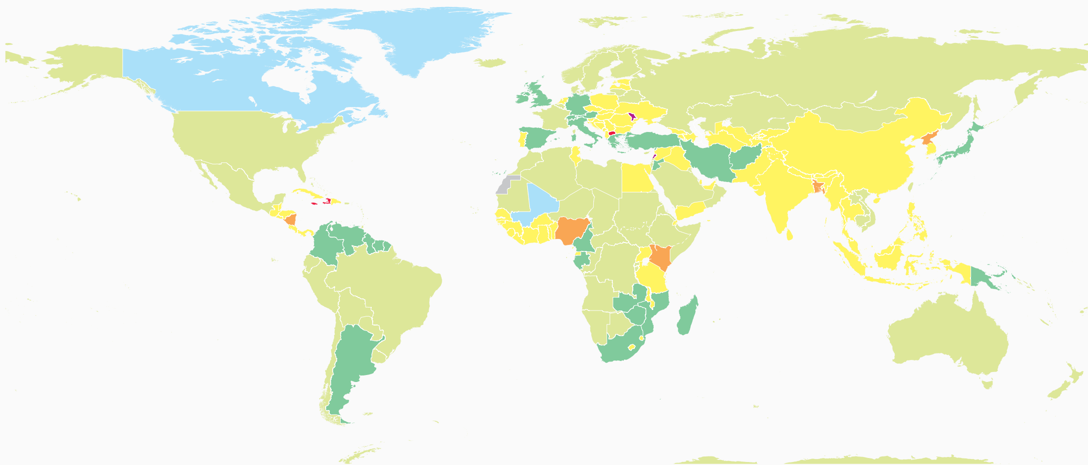
While releases of the POPs first listed under the Stockholm Convention have decreased in most higher-income countries, some compounds continue to be manufactured and released in lower-income countries. For example, DDT is manufactured in India and continues to be used also in some African countries for disease vector control. According to the effectiveness evaluation of the Stockholm Convention, the Convention is expected to result in decreasing levels of unintentional POPs in all regions. Data on releases of unintentionally produced POPs at different times, especially from developing countries and economies in transition, is limited, although initial results show positive trends (UNEP and Secretariat of the Stockholm Convention 2017).

PCDD/PCDF (classified as human carcinogens by the International Agency for Research on Cancer) are not commercially produced, but are formed as trace amounts of undesired impurities in the manufacture of other chemicals or during combustion processes. PCDD/PCDF are released from a variety of sources, with open burning of waste by far the most significant source of emissions to air, particularly in developing countries (Fiedler 2007). According to the effectiveness evaluation of the Stockholm Convention, reported releases of PCDD/PCDF remained almost unchanged between the baseline (2001-2011) and the update (2001-2015). The Asia-Pacific region reported the highest increase and the Western Europe and Others region the strongest decline (Secretariat of the Stockholm Convention 2017). A 2016 study (Wang *et al.* 2016) provided a global estimate of PCDD/PCDF releases. Figure 5.3 shows the releases per unit area that account for the observation that the environmental burden from the release of a certain amount of PCDD/PCDF generally depends on the size of the area to which the release occurs. While the highest releases were estimated to be in Asia, per capita releases in that region were below the global

**Box 5.1 Outcomes of the effectiveness evaluation of the Stockholm Convention (UNEP and Secretariat of the Stockholm Convention 2017, p. 4)**

The effectiveness evaluation of the Stockholm Convention made available in 2017 found, among other outcomes, that "monitoring results indicate that regulations targeting POPs are succeeding in reducing levels of POPs in humans and the environment. For POPs listed in 2004 under the Convention, concentrations measured in air and in human populations have declined and continue to decline or remain at low levels due to restrictions on POPs that predated the Stockholm Convention and are now incorporated in it. For the newly listed POPs, concentrations are beginning to show decreases, although in a few instances, increasing and/or stable levels are observed".

**Figure 5.3** **National/regional PCDD/PCDF releases per unit area (adapted from Wang *et al.* 2016, p. 307)**



Release per unit area (mg Toxic Equivalent (TEQ) $km^{-2} yr^{-1}$)

Reprinted with permission from Elsevier

0.001–0.1 (4) 0.1–0.5 (41) 0.5–1 (32) 1–5 (79) 5–10 (21) 10–15 (9) 15–28.2 (10)

average; by contrast, while the lowest releases were estimated to be in Oceania, this region was estimated to have the highest releases per capita (also due to non-anthropogenic sources).

## Atmospheric emissions of mercury are a significant source of air pollution

It is estimated that cumulative global anthropogenic releases of mercury to the environment up to 2010 amounted to about 1.54 million tonnes, 73 per cent of which had been emitted since 1850 (Streets *et al.* 2017). Anthropogenic mercury emissions to the atmosphere are currently more than 2,000 tonnes per year, or about 30 per cent of total annual global atmospheric mercury emissions. A significant share of these emissions comes from industrial areas in East and South Asia, Central Europe, South Africa and eastern North America. The remainder come from natural processes (60 per cent) that result in re-emissions of mercury previously deposited to soils and water (much of which are derived from earlier anthropogenic emissions and releases) and from natural sources (10 per cent) (UNEP and AMAP 2017).

Artisanal and small-scale gold mining (ASGM) is also a significant source of mercury released to air: 37 per cent of global air emissions of mercury are produced by ASGM. Mercury vapour in the air around amalgam burning sites almost always exceeds the WHO limits for public exposure (Gibb and O'Leary 2014). Other important sources of mercury emissions include stationary coal combustion, power plants, vinyl chloride monomer production, industrial uses and domestic/residential burning. These are followed by emissions from non-ferrous metal production and from cement production. Emissions associated with the disposal of mercury-containing product waste make up some 7.6 per cent of the air emissions (UNEP and AMAP 2017).

Global mercury emissions show a slow decline with regional differences. Significant decreases in emissions in Europe and North America are offset by increases in Asia. Trends observed in North America and Europe reflect the phase-out of mercury from commercial products, the closing of coal-fired power plants, and improved pollution controls on remaining coal-fired utilities (Zhang *et al.* 2016).

### Releases from waste dumps are a key source of air pollutants

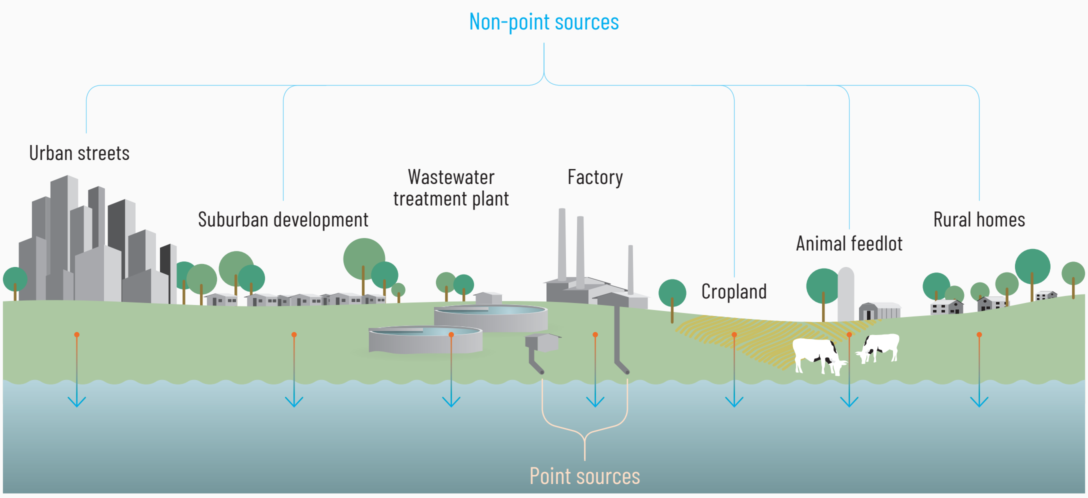
Roughly 33 per cent of the world's solid waste ends up in open dumpsites. Decomposition of waste in dumps and landfills releases various volatile chemicals originating from decomposing products, as well as a heavy mix of methane and $CO_2$. It is estimated that GHG emissions of 1.6 billion tonnes $CO_2$-eq. were generated from solid waste treatment and disposal in 2016, driven primarily by open dumping and disposal in landfills. This is about 5 per cent of total global GHG emissions (Kaza *et al.* 2018). As urbanization and population growth continue, it is expected that these dumpsites will increase in size and number and that, by 2025, municipal and domestic dumps will account for 8-10 per cent of global anthropogenic GHG emissions (International Solid Waste Association [ISWA] 2015).

Open burning is common in many low-income countries (Kumari *et al.* 2017; Wang *et al.* 2017). An estimated 620 million tonnes of global domestic waste are burned openly every year (Cogut 2016). Burning of this waste, typically at low temperatures and in an uncontrolled manner, releases large amounts of hazardous substances to the environment, making dumps a major source of some substances of high concern such as carbon black, dioxins and furans (Zhang *et al.* 2017). Given the difficulty of including open dump burning in inventories, air emissions from waste dumps are significantly underestimated (Wiedinmyer *et al.* 2014).

### Hazardous chemicals are also released indoors

In many lower-income countries fuel combustion for cooking and heating is the primary source of indoor air contamination in homes (WHO 2014). However, in higher-income consumer economies the most common sources of indoor air contaminants (in addition to cigarettes) are building materials, household furnishings and products. For example, formaldehyde volatilizes from pressed wood products and biocides leach from indoor carpeting. Phthalates such as DEHP are widely released to indoor air, including dust from flooring materials (Jeon, Kim and Choi 2016). The growing use of building insulation materials, which are increasingly installed to conserve energy, has introduced new health concerns related to contaminates in household dust coming from the aging of the insulation. Products such as perfumes, hairsprays, air fresheners, furniture polish, cleaning solvents, hobby and craft supplies, pesticides, glues, adhesives, sealants, and carpet and fabric dyes and fibres are all likely sources of VOCs in indoor air (Apte and Salvi 2016).

**Figure 5.4** Potential sources of chemical water pollution (adapted from Arefin and Malik 2018, p.100)



The WHO has identified the most common chemicals emitted to household indoor air globally. These include benzene, carbon monoxide, formaldehyde, naphthalene, nitrogen dioxide, polyaromatic hydrocarbons, trichloroethylene and tetrachloroethylene (WHO 2010).

### 5.1.2 Releases to freshwater and oceans

Manufactured chemicals contaminate water bodies through direct discharges from industrial facilities and municipal wastewater treatment plants, as well as indirect discharges from landfills and leaking pipes and storage tanks. Non-point sources such as agricultural fields, roadways and parking lots are harder to identify and control (Arefin and Malik 2018) (Figure 5.4). Chemicals are also released to water through wastewater containing commonly used commercial products such as soaps, detergents and personal care products flushed through municipal sewage treatment facilities.

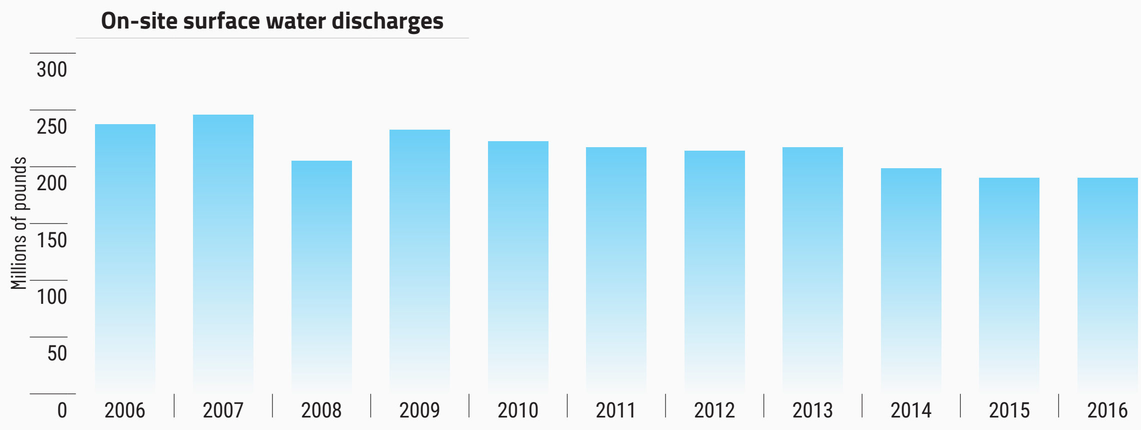
#### Releases of chemical wastes to water bodies throughout the world remain significant

It is estimated that globally more than 80 per cent of municipal and industrial wastewater is released to the environment without adequate treatment (United Nations Educational, Scientific and Cultural Organization [UNESCO] 2017). In lower-income countries the rates are even higher. Up to 90 per cent of industrial and agricultural wastewater in these countries flows untreated into rivers, lakes and coastal zones; it is also estimated that globally 2 million tonnes of sewage and industrial and agricultural wastes are discharged into freshwater bodies every day. Facilities thus represent a major point source of releases. For example, 80-90 per cent of PFOS/PFOA contamination in the Chinese environment has been estimated as originating from manufacturing and industrial facilities, primarily via wastewater discharges (Liu *et al.* 2017). Agriculture is a leading source of nitrogen pollution and nitrate has been identified as the most common chemical contaminant in the world's groundwater aquifers (Shukla and Saxena 2018).

"China has been the largest producer and emitter of perfluorooctanoic acid and its salts (PFOA/PFO)" (Meng *et al.* 2017, p. 11254). A study showed that in 2012 most PFOA releases in China are due to the activities of the fluorochemical industry (94 per cent) rather than releases from consumer products containing PFOA (Li *et al.* 2015); however, this situation may have changed over the past years.

While releases of hazardous chemicals to surface waters remain high in most countries, rates are falling in the United States, Japan and northern Europe. According to the TRI in the United States,

**Figure 5.5** **On-site hazardous surface water discharges in the United States reported to the Toxics Release Inventory (TRI) (millions of pounds), 2006-2016 (adapted from US EPA 2019, p. 44)**



hazardous surface water discharges in that country fell by 24 per cent (60 million pounds) between 2006 and 2016. Most of the decrease was due to reductions in water discharges of nitrate compounds from agriculture, which declined by 25 per cent (56 million pounds) and were attributable to reduced nitrification and nitric acid formation in wastewater treatment facilities (US EPA 2019) (Figure 5.5).

### Agricultural production is the primary source of surface water pollution globally

In many higher-income countries and most lower-income ones, pollution from agriculture exceeds that from municipal and industrial discharges. Farming and food processing generate some 40 per cent of water pollution in higher-income countries and 54 per cent in lower-income countries (UNESCO 2009). In the United States agriculture is the main source of water pollution of lakes, rivers and streams, the second largest source in wetlands, and the third largest source in lakes (Mateo-Sagasta *et al.* 2017). In the EU water quality in 38 per cent of water bodies has been degraded by agricultural runoff (UNESCO 2015). Agriculture is the source of a large share of surface water pollution in China, where it is responsible almost exclusively for groundwater pollution by nitrogen (Mateo-Sagasta *et al.* 2017).

Herbicides, insecticides, fungicides and bactericides applied directly in fields can wash off soil into nearby surface water or percolate to lower soil layers and groundwater. However, the intensity of pesticide use globally has been falling (see Part I, Ch. 5). The growth of intensive livestock production has introduced a new class of agricultural pollutants released to the environment: veterinary medicines such as antibiotics, vaccines and growth promoters contaminate both surface and groundwater. Such pollution has become significant as soil and water contaminants near large-scale animal feed lots and industrial-scale egg and meat production facilities (Boxall 2012).

### Releases of pharmaceuticals to water are an emerging concern

About 4,000 active pharmaceutical ingredients are administered worldwide in prescription medicines, over-the-counter therapeutic drugs and veterinary drugs. Globally some 100,000 tonnes of active ingredients are produced every year (Weber *et al.* 2014). A large number of studies document the pollution of rivers and groundwater (as well as soil and sediment) with active pharmaceutical ingredients from pharmaceutical manufacturing in different regions (Larsson 2014). Conventional wastewater treatment facilities are often ineffective in fully removing pharmaceuticals from wastewater, with removal efficiencies ranging from 20 to 80 per cent for individual pharmaceuticals (Owens 2015; Beek *et al.* 2016). Antibiotics and synthetic hormones are widely used in humans and animals; once excreted, they are released directly to surface water or waste treatment facilities. Additional burdens to water arise

when unused medicinal products in domestic settings are disposed of in sinks and toilets (Review on Antimicrobial Resistance [Review on AMR] 2016). Yet another critical source of antibiotics is animal husbandry, including fish farming (Singer *et al.* 2016; Wall *et al.* 2016; Topp 2018). In some countries the use of antibiotics in agriculture exceeds its use in humans (Review on AMR 2016). Scientists have highlighted the need to address knowledge gaps regarding the role of the environment in the transmission of antibiotic resistant pathogens, including regarding release pathways (Larsson *et al.* 2018).


### Groundwater pollution resulting from chemical discharges remains significant

Despite considerable progress globally in reducing discharges of chemical pollutants to aquifers and water collection basins, pesticides, industrial chemicals and household chemicals continue to affect the quality of regional groundwater in many areas. Hazardous chemicals used in industry and commercial products such as solvents (particularly trichloroethylene, perchloroethylene and methylene chloride) are a common source of groundwater contamination. There are growing concerns about groundwater contamination by the chemicals used in hydraulic fracturing (Michalski and Ficek 2016; Luek and Gonsior 2017) (Box 5.2).

### Discharges from land-based sources into oceans

Roughly 80 per cent of ocean pollution comes from land-based sources. This includes much of the world's urban sewage, which is often discharged untreated into the ocean. In many lower-income countries between 80 and 90 per cent of municipal sewage entering coastal zones is estimated to be raw and untreated. Nearly 50 per cent of the urban sewage discharged to the Mediterranean Sea is untreated (EC 2006). This sewage often contains heavy metals such as lead, cadmium and mercury, as well as a variety of POPs found in conventional domestic and commercial products (US NOAA 2018). In addition, plastic waste washed through wastewater treatment facilities contains a broad range of additive chemicals. Contaminants may also be re-emitted/remobilized in the marine environment. Tornero and Hanke (2016) lists 276 substances potentially released into the sea from sea-based sources.

**Box 5.2 Releases of chemicals used in fracking**

Hydraulic fracturing (fracking) has expanded natural gas production, particularly in the United States. The use of additives in the fluids used to fracture rock formations is causing increasing concern. Some of these additives have been shown to migrate into groundwater (i.e. drinking water resources) (USGS 2016). While the oil and gas industry has been reluctant to divulge the ingredients of these fluids, it has been suggested that upwards of 750 substances could be found in fracking fluids, ranging from benign salt and citric acid to benzene, toluene, xylene and lead. Methanol is the most common component, but other chemicals include hydrochloric acid, isopropyl alcohol, 2-butoxyethanol and ethylene glycol (United States House of Representatives 2011; Michalski and Ficek 2016). Hydraulic fracturing involves five stages, each of which potentially causes water pollution (US EPA 2016; Luek and Gonsior 2017).

### Large amounts of plastic are released to water bodies along various pathways

Plastic enters the oceans along various pathways. Land-based sources (e.g. waste disposed at beaches) are the largest source of releases to the marine environment; others include marine-based sources (e.g. due to aquaculture and fishing) and other environmental media (rivers and atmospheric transport) (Lebreton *et al.* 2017). Studies suggest that about 6-10 per cent of global plastic production is released to the ocean (Essel *et al.* 2015). Van der Wal *et al.* (2015) found that the Danube River released between 530 and 1,500 tonnes of plastics into the Black Sea each year. It has been estimated that 275 million tonnes of plastic waste were generated in coastal countries in 2010, of which 4.8 to 12.7 million tonnes entered the ocean (Jambeck *et al.* 2015). The total mass of plastic debris added to the marine environment from 2010 until 2025 is expected to grow by an order of magnitude and may amount to some 100-250 million tonnes (UNEP and Grid Arendal 2016).

Macroplastic litter originates from various sources, including poorly managed plastic recycling, packaging, agriculture, construction and coastal tourism (UNEP 2016b). Recent modelling studies suggest that the largest share of microplastic wastes that end up in the ocean are secondary wastes generated from the breakdown of clothing and textiles during machine washing (around 35 per cent) and erosion of tyres on roadways during normal vehicular travel (around 29 per cent). A smaller but significant share comes from primary microbeads added as functional constituents to detergents and personal care products (Boucher and Friot 2017) (Figure 5.6).

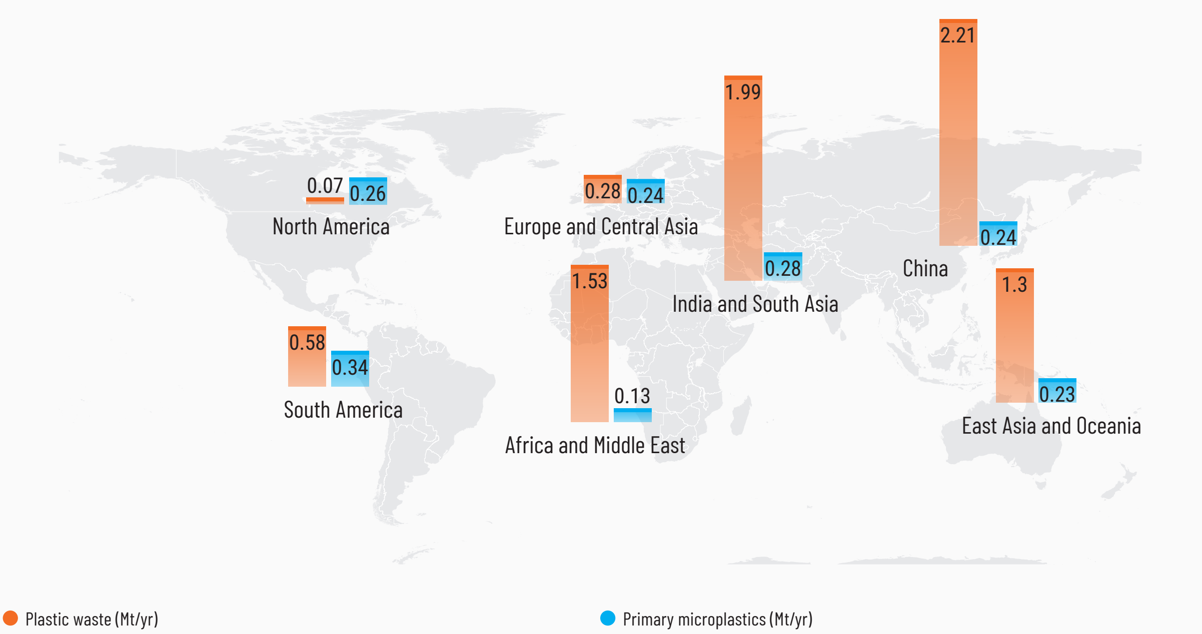
## 5.1.3 Releases to soil

Hazardous chemicals are released to soil during activities such as agriculture, mining, manufacturing and treatment of sewage sludge, or as solid and hazardous wastes deposited in dumps and landfills. Conventional applications of pesticides and fertilizers in agriculture result in direct releases of pesticides to soil (Rodríguez Eugenio, McLaughlin and Pennock 2018).

### Releases to soil through mining and metal processing are very significant

The mining industry generates large amounts of overburden and mining wastes. The mining and metal processing industries are responsible for the largest releases of hazardous pollutants in

**Figure 5.6** Global releases of plastic and microplastic waste to oceans (million tonnes per year) (adapted from Boucher and Friot 2017, p. 28)



North America. The top five pollutants in 2013 reported to PRTRs In North America (Canada, the United States and Mexico) were zinc and its compounds, lead and its compounds, manganese and its compounds, copper and its compounds, and nitric acid and its compounds, all of which are found in mining wastes (Commission for Environmental Cooperation 2016). Of the reported chemicals released to the environment in the United States, 44 per cent (1.52 billion pounds) came from the metal mining industry; most of this was deposited on land as overburden and waste (US EPA 2018).

Wastes from mining often contain hazardous chemicals such as arsenic, lead and cyanide in concentrations that pose serious hazards to ecosystems and human health. Acid mine drainage (AMD) is one of the largest sources of the mining industry's soil and water pollution (Hudson-Edwards *et al.* 2011). In many parts of the world gold, gems, precious stones and metals are extracted by artisanal and small-scale miners. About 25 per cent of the world's gold is produced through artisanal and small-scale gold mining (ASGM) operations in over 55, mostly lower-income countries. Mercury releases from tailings and vaporized mercury at these mines exceed 1,000 tonnes per year, making ASGM responsible for the largest releases of mercury to the soil of any sector globally (Esdaile and Chalker 2018).

### Total fertilizer and pesticide applications to soil are increasing, but application rates are decreasing

Because use of fertilizers and pesticides typically involves direct application to crops, trends in their use are a rough indicator of the volumes released to soils. As explored in Part I, Chapter 2, the market for pesticides and fertilizers is increasing globally. Between 2018 and 2022 the fertilizer industry is expected to add 78 million tonnes of production capacity. Global manufacture of pesticide active ingredients increased from 1.9 million tonnes in 2008 to 2.8 million tonnes in 2016.

Meanwhile, it has been estimated that use rates have declined over the past decades. A 2018 report (Phillips McDougal 2018), estimated average application rates in the 1950s at 1,200, 1,700 and 2,400 grams of active ingredient used per hectare (g ai/ha) for fungicides, insecticides, and herbicides, respectively. By the 2000s the average use rates were reduced to 100, 40, and 75 (g ai/ha) (Figure 5.7). Schreinemachers and Tipraqsa (2012) studied levels and trends in agricultural pesticide use for a large cross-section of countries using FAO data for the period 1990-2009. Their analysis showed that a 1 per cent increase in crop output per hectare was associated with a 1.8 per cent increase in pesticide use per hectare, and that the growth in intensity of pesticide use levelled off as countries reached a higher level of economic development. On the other hand, few higher-income countries had significantly reduced the

**Figure 5.7** Average active ingredient application rates over time as a function of the decade of introduction, 1950s-2000s (adapted from Phillips McDougal 2018, p. 6)

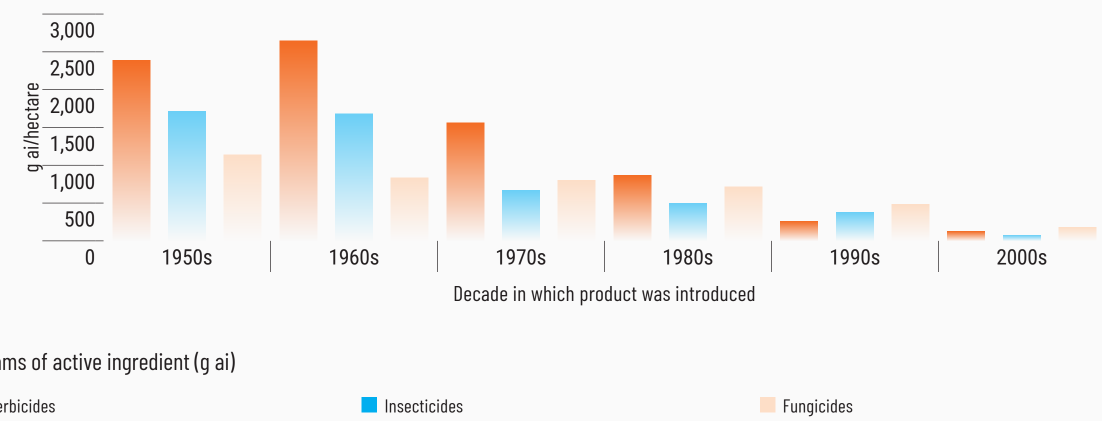
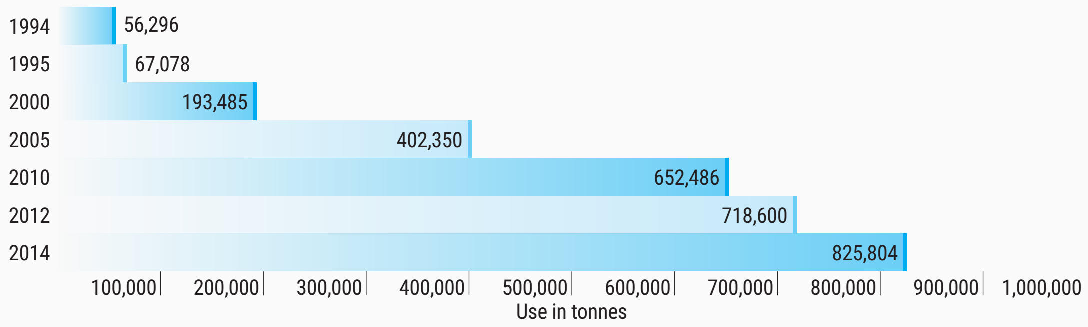


**Figure 5.8** Global glyphosate use, 1994-2014 (tonnes) (based on Benbrook 2016)




level of intensity of their pesticide use since decreases in insecticide use were largely offset by increases in herbicide and fungicide use.

The FAO maintains a database for the purpose of tracking pesticide use by country, but few data have been uploaded. A study in the United States on trends in pesticide use for 21 of that country's largest-volume crops found that use increased from the 1960s to 1980 and levelled off thereafter, at some 500 billion pounds per year. Herbicides made up the largest share of the pesticides, and the most common herbicides were glyphosate-based (Fernandez-Cornejo *et al.* 2014). Glyphosates are the largest-volume herbicides in use today (Benbrook 2016). Figure 5.8 shows the significant growth of glyphosate use worldwide.

Trace elements such as cadmium, boron and iron are increasing in agricultural soils where there has been prolonged use of rock phosphate and phosphorus-containing fertilizers (Kratz, Schick, and Schnug 2016). Increased use of treated municipal sewage can also distribute various heavy metals, including lead and cadmium, to soil (Najam *et al.* 2015).

### Microplastics are another source of soil pollution

If discarded plastic is not incinerated, most of it ends up in dumps and landfills where it may disintegrate into microplastic particles (commonly understood to be 5 millimetres in diameter or less) that break down further into nanoparticles (between 1 and 100 nanometres [i.e. between 0.001 and .01 micrometre] in size). According to de Souza Machado *et al.* (2018) one-third of all plastic waste ends up in soils or freshwater. Municipal sewage systems distribute microplastics both in wastewater and sludge. It is estimated that 80-90 per cent of the microplastics in municipal sewage ends up in the sludge that is typically spread on farms or forests (de Souza Machado *et al.* 2018). Zhang and Liu (2018) identified soil amendments and irrigation with wastewater as important sources. Application of sewage sludge was also identified by the Norwegian Institute for Water Research (2018) as an important source of releases of microplastics to agricultural soils and estimated that 110,000-730,000 tonnes of microplastics are released each year to agricultural soils in Europe and North America.

## 5.2 Chemical releases from products

### Chemicals are released during production, use and disposal of products

Chemicals in products are released during product manufacturing, expected use and disposal, or during product transportation, storage, accidents or unintended uses. Releases from products are diffuse, and quantifying the amount of these releases is challenging. However, some releases from products have been well-studied. For example, mercury-containing products were recognized as significant contributors to global mercury releases to air, soil and water from the late 19th century onwards. Given the diversity and magnitude of the products currently in commerce, chemical releases from products are receiving yet further attention. New research is examining the respective contributions of consumer products to total global emissions, as well as the contributions of specific chemicals such as those used as flame retardants (Wei *et al.* 2015) and plastic articles (Steinemann 2015; Cousins *et al.* 2018).

### Releases from products are a substantial part of total emissions

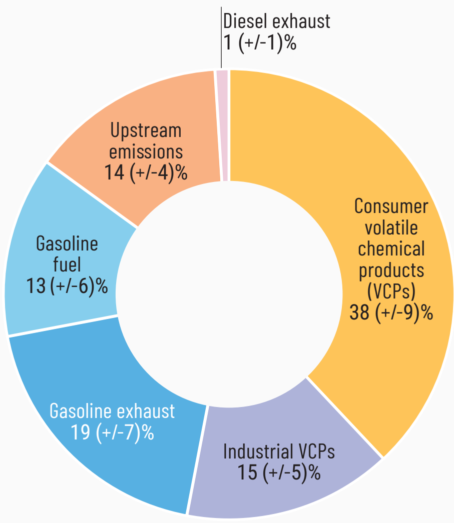
Volatile and non-volatile organic compounds (VOCs and NVOCs) released from products are a major source not only of indoor air pollution, but also of pollution of outdoor air and freshwater and marine environments. A recent study suggests that releases of chemicals from consumer products (e.g. cosmetics and paints) have become the primary source of VOCs from petrochemical sources in some industrialized cities (McDonald *et al.* 2018) (Figure 5.9). The amount of chemicals released to the environment from products varies substantially, depending on product applications and chemical properties. A combination of modelling and empirical approaches has been used to trace specific chemical sources from products to environmental media (e.g. flame retardants in products that can reach water bodies) (Csiszar *et al.* 2014; Melymuk *et al.* 2014).

### Volatile and semi-volatile compounds volatilize from articles and building products

Chemically-intensive products such as furniture, carpets, textiles, toys and building products contain a diverse collection of chemical ingredients. These products are important sources of chemical releases. People are in regular proximity to or in contact with such products. Plastic products, in particular, are a common source of chemical releases indoors and outside. Because polymerization of monomers is rarely complete, and additives may not be chemically linked into the polymeric structure, unreacted monomers, plasticizers, binders, flame retardants, dyes, colorants, nanoparticles, biocides and contaminants from processing can leach from plastic products (Rydberg *et al.* 2011). Direct human exposure to plastic components also occurs, especially in the case of children through toy mouthing or dermal contact (Bouma and Schakel 2002; Babich *et al.* 2004).

VOCs such as phenol or benzene diffuse relatively rapidly through a product and are

**Figure 5.9** **Contributors to VOC emissions to ambient air in Los Angeles, California, 2010 (adapted from McDonald *et al.* 2018, 763)**




Volatile organic compound emissions = 350 +/- 50 Gigagrams (Gg).
Reprinted with permission from the American Association for the Advancement of Science (AAAS).

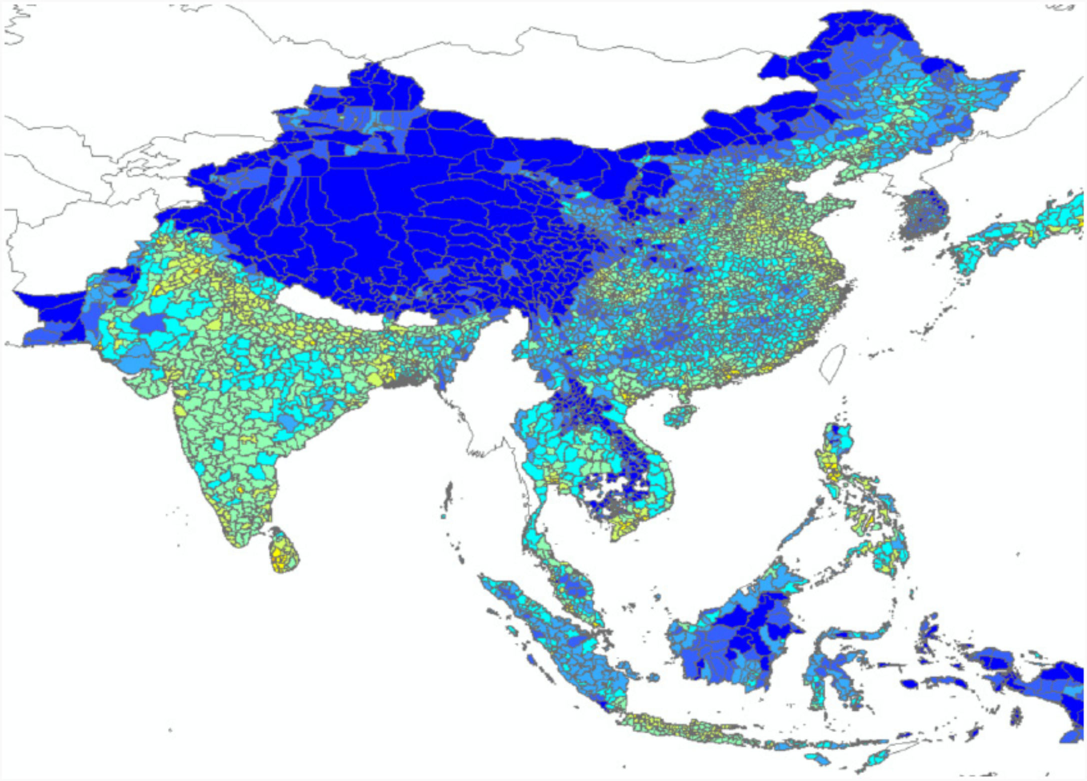
often entirely released to indoor air over the product lifetime, leading to emissions to ambient urban air (McDonald *et al.* 2018). The amount and rate of release of such VOCs are driven by the diffusion characteristics within the material, which depends on chemical properties, material type and temperature (Huang and Jolliet 2016; Huang *et al.* 2017).

Semi-volatile organic compounds (SVOCs), such as phthalates and several classes of flame retardants, are released to indoor air from products more slowly and in smaller fractions due to their lower atmospheric vapour pressure. Exposure to these compounds can, however, cause concern due to their relatively large content in products and to exposure via dust or gaseous dermal uptake (Weschler and Nazaroff 2014; Morrison *et al.* 2016). In addition, a substantial part of SVOCs is present at the end of the product lifetime. It can then be released to the environment during disposal (e.g. landfilling or incineration).

### Personal care and household chemical releases

In many consumer economies indoor air is increasingly polluted with releases of VOCs from products such as perfumes, hairsprays, air fresheners, furniture polish, cleaning solvents and household biocides. Chemicals in personal care products are directly released during normal use through dermal contact. Of particular concern are skin lightening creams that contain mercury, which are commonly used in some Asian and African countries. In one study the WHO found that 40 per cent of women in China, 61 per cent in India and 76 per cent in Nigeria used such creams (WHO 2011). A large share of the substances in personal care products can be washed off. They may then reach freshwater and marine environments. Figure 5.10 presents findings on the geographical distribution of releases of linear alkylbenzene sulphonate (LAS), primarily from the use of biodegradable laundry detergents in China. Spatially explicit chemical release inventories are becoming available at the global level to estimate releases

**Figure 5.10** **Spatial distribution of releases of linear alkylbenzene sulphonate (LAS) due to household emissions in Asia, in mg/m²/day (underlying data from Wannaz *et al.* 2018, elaborated according to Hodges *et al.* 2014)**



0.0e+000–3.8e-003
3.9e-003–1.5e-002
1.6e-002–5.1e-002
5.2e-002–1.6e-001
1.7e-001–4.9e-001
5.0e-001–1.5e-000
1.6e+000–4.6e+000
4.7e+000–1.4e+001
1.5e+001–4.3e+001
4.4e+001–1.3e-002

from household products to the freshwater environment, accounting for the presence or type of wastewater treatment processes (Hodges *et al.* 2014; Wannaz *et al.* 2018) (Figure 5.10).

## Migration from packaging to food

Chemical releases to food occur unintentionally from packaging materials (e.g. releases of bisphenol A [BPA] or bisphenol S [BPS] from plastic water bottles). The EU's Rapid Alert System for Food and Feed (RASFF) shows a significant upward trend in the migration of hazardous chemicals from materials in contact with food, including migration of lead from ceramic ware; releases of chromium and nickel from metal ware; migration of isopropyl thioxanthone from carton packages; and releases of aromatic amines from kitchen utensils (EC 2014). Research indicates that food packaging contributes to measurable levels of phthalates in take-out foods in the United States (Varshavsky *et al.* 2018).

## Product distribution transports chemicals throughout the world

Many products formulated or assembled in one region are transported worldwide. If they contain hazardous chemicals, they may become a vehicle for transporting these chemicals to distant users and landfills. There the chemicals may be released and pollute local ambient and indoor environments. Where supply chains are long and involve transporting chemicals or components across continents, they can be responsible for a significant share of the transfer of hazardous chemicals throughout the environment. This is further explored in Part I, Ch. 4.

### Chemicals accumulate in human-made material stocks, creating potential legacies

A significant share of materials accumulates in "human-made material stocks" (buildings, infrastructure and machinery). It was estimated that 36 billion tonnes of such materials were added to the global material stock in 2015 alone (Krausmann *et al.* 2017a). The total mass of the human-made infrastructure has been estimated at about 30 trillion tonnes (Zalasiewicz *et al.* 2016). Large quantities of chemicals are thus stored in the accumulated products of societies around the world and, over time, may lead to substantial releases to the environment (Rydberg *et al.* 2011). In many cases these materials contain chemicals of concern (e.g. certain building materials containing asbestos).

When products are disposed, the majority of materials (and the chemicals in them) are dispersed as releases to the environment and/or unrecoverable wastes. Only around 8.4 billion tonnes or 9.1 per cent of global material resources used in 2015 were recycled (de Wit *et al.* 2018). Consistent with this trend, less than 9 per cent of the 6.3 billion tonnes of plastic waste generated up to 2015 has been recycled, while 12 per cent has been incinerated and 79 per cent has been disposed in landfills or in the environment (Geyer, Lambeck and Law 2017). Where persistent chemicals such as brominated and fluorinated compounds, and metals such as mercury, lead and other heavy metals, are incorporated into products that are disposed in the environment as wastes, the potential for exposures of people and biota may persist for decades.

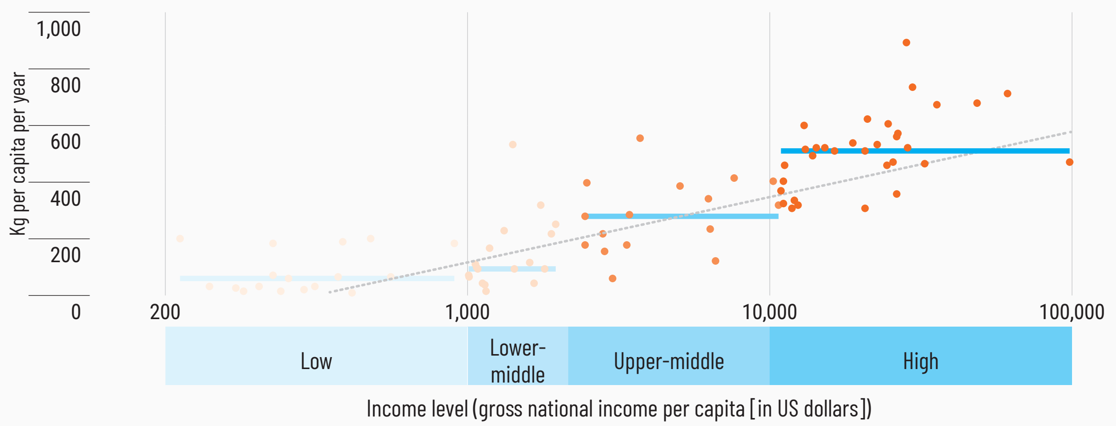
## 5.3 Releases from municipal and hazardous waste

Large volumes of manufactured chemicals are deposited on soil as hazardous or solid wastes. Industrial wastes that are flammable, reactive, corrosive or toxic to human health or the environment are considered to be hazardous wastes. Solid wastes are typically divided into municipal (or household) wastes, commercial wastes, industrial wastes, and construction and demolition wastes. As the proportion of discarded chemically intensive products (e.g. motor oil, batteries, paints and varnishes, cleaning agents, electronic products, solvents and pesticides) increases, municipal wastes are becoming as hazardous as hazardous wastes.

### Municipal solid waste is increasing, particularly in lower-income countries

The best estimate of the global amount of municipal solid waste is around 2.1 billion tonnes per year with at least 33 per cent of that amount not managed in an environmentally safe manner (Kaza *et al.* 2018). If commercial, industrial, and construction and demolition wastes are included, the estimates grow to 7 to 10 billion tonnes per year. Globally, some 37 per cent of municipal solid waste is disposed of in some form of a landfill, 8 per cent of which is disposed of in sanitary landfills with landfill gas collection systems. Open dumping accounts for about 33 per cent of waste, 19 per cent is recovered through recycling and composting, and 11 per cent is incinerated for final disposal. (Kaza *et al.* 2018). In lower-income countries indiscriminate dumping of solid and liquid waste by industry, small-scale

**Figure 5.11** **Waste generation by level of national income (US dollars) (adapted from UNEP and ISWA 2015a, p. 2)**




Note: Data for selected countries

artisans and automotive garages is common, as proper waste collection and disposal facilities are lacking. In rural areas most wastes are burned in open dumps or directly released to unmanaged landfills, leading to contaminated soils, surface waters and groundwater (ISWA 2015; ISWA 2016).

Although waste generation rates and measures vary significantly across countries, there is generally a positive correlation between waste generation and national income level. In 2010 the traditional higher-income countries, with 16 per cent of the world population, accounted for about 34 per cent (or 683 million tonnes) of the world's solid waste. Low-income countries accounted for 9 per cent of the world population, but generated 93 million tonnes or about 5 per cent of global solid waste (UNEP and ISWA 2015a; Kaza *et al.* 2018) (Figure 5.11).

China generated some 203.6 million tonnes of municipal solid (consumption) waste in 2016 (National Bureau of Statistics of China 2017). By 2030 it will likely produce twice as much municipal solid waste as the United States. Sub-Saharan Africa generates approximately 174 million tonnes per year. The total amount of waste generated per year in Latin America and the Caribbean is 231 million tonnes, while In East Asia and the Pacific the amount generated per year is at least 468 million tonnes (Kaza *et al.* 2018).

In terms of chemical-intensive products in global municipal waste streams, plastics are estimated to make up 8 to 12 per cent across most countries, while the proportion of paper varies from a high of 23 per cent in higher-income countries to 11 per cent in middle-income countries and a low of 7 per cent in lower-income countries. Metals and textiles make up about 12 per cent of municipal waste generated in higher-income countries, 9 per cent in middle-income countries and 6 per cent in lower-income countries. Estimates suggest that household hazardous wastes make up less than 1 per cent of municipal wastes, but up to 5 per cent if electronic waste (e-waste) is included (UNEP and ISWA 2015a).

Global solid waste is expected to grow to 3.40 billion tonnes by 2050. In projecting trends beyond 2015, the *Global Waste Management Outlook* (UNEP and ISWA 2015a) shows a flattening of the growth curve and, in some cases, a decline of municipal waste generation rates in higher-income countries, while such rates are growing and expected to continue to grow

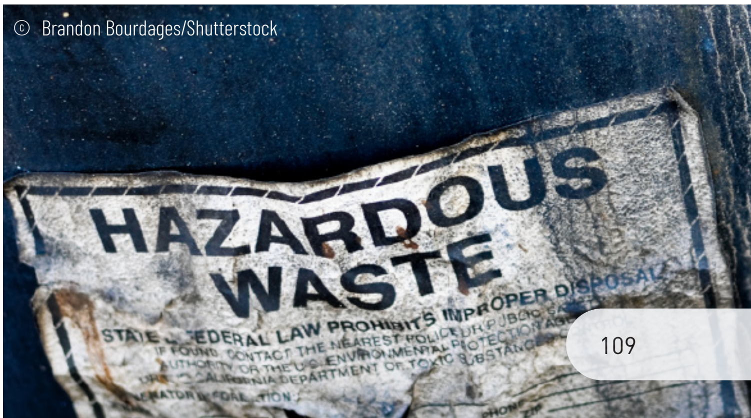


**Table 5.1** Hazardous and non-hazardous wastes from six African countries (tonnes/year), 2012 (based on United Nations Economic and Social Commission for Western Asia 2015, p. 19)

| | Non-hazardous waste (tonnes/year), 2012 | Hazardous waste (tonnes/year), 2012 |
|---|---|---|
| Algeria | 10,430,000 | 2,910,000 |
| Morocco | 69,070,000 | 1,910,400 |
| Egypt | 51,000,000 | 6,528,300 |
| Tunisia | 6,555,000 | 166,000 |
| Mauritania | 540,000 | 126,000 |
| Sudan | 1,528,000 | not available |

in middle- and lower-income countries. Daily per capita waste generation in higher-income countries is projected to increase by 19 per cent by 2050, compared to lower- and middle-income countries where it is anticipated to increase by approximately 40 per cent or more.

Asian counties are expected to become the largest generators of municipal waste by 2030, while Africa is expected to exceed even these rates by later in the century (UNEP and ISWA 2015b; Kaza *et al.* 2018). The social and economic megatrends driving African development are affecting the continent's waste generation. 125 million tonnes of municipal solid waste was generated in African countries in 2012 and that amount is expected to double by 2025. Table 5.1 presents data on hazardous and non-hazardous wastes from six African countries (United Nations Economic and Social Commission for Western Asia 2015).

On average, some 57 per cent of these wastes are organic material while 13 per cent are plastic. More than 90 per cent are disposed in uncontrolled dumpsites and landfills. An estimated 70-80 per cent are recyclable, but only 4 per cent are reported to be currently recycled (Figure 5.12).

## Solid waste recycling is increasing around the world

Waste recycling is considered a benefit to environmental sustainability and a critical component of a circular economy. The rates of municipal waste recycling vary considerably among countries, from a high of 65 per cent in

**Figure 5.12** Composition of municipal solid waste in Sub-Saharan Africa (per cent) (adapted from UNEP and Council for Scientific and Industrial Research [CSIR] n.d., p. 2)

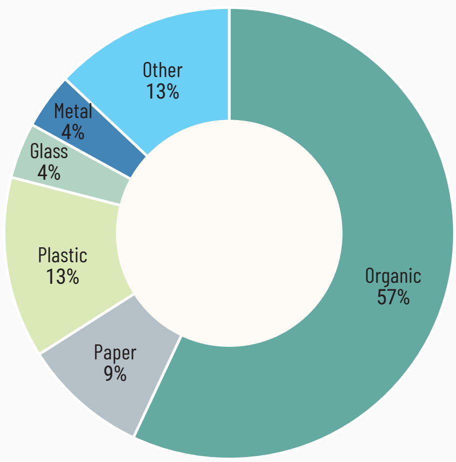
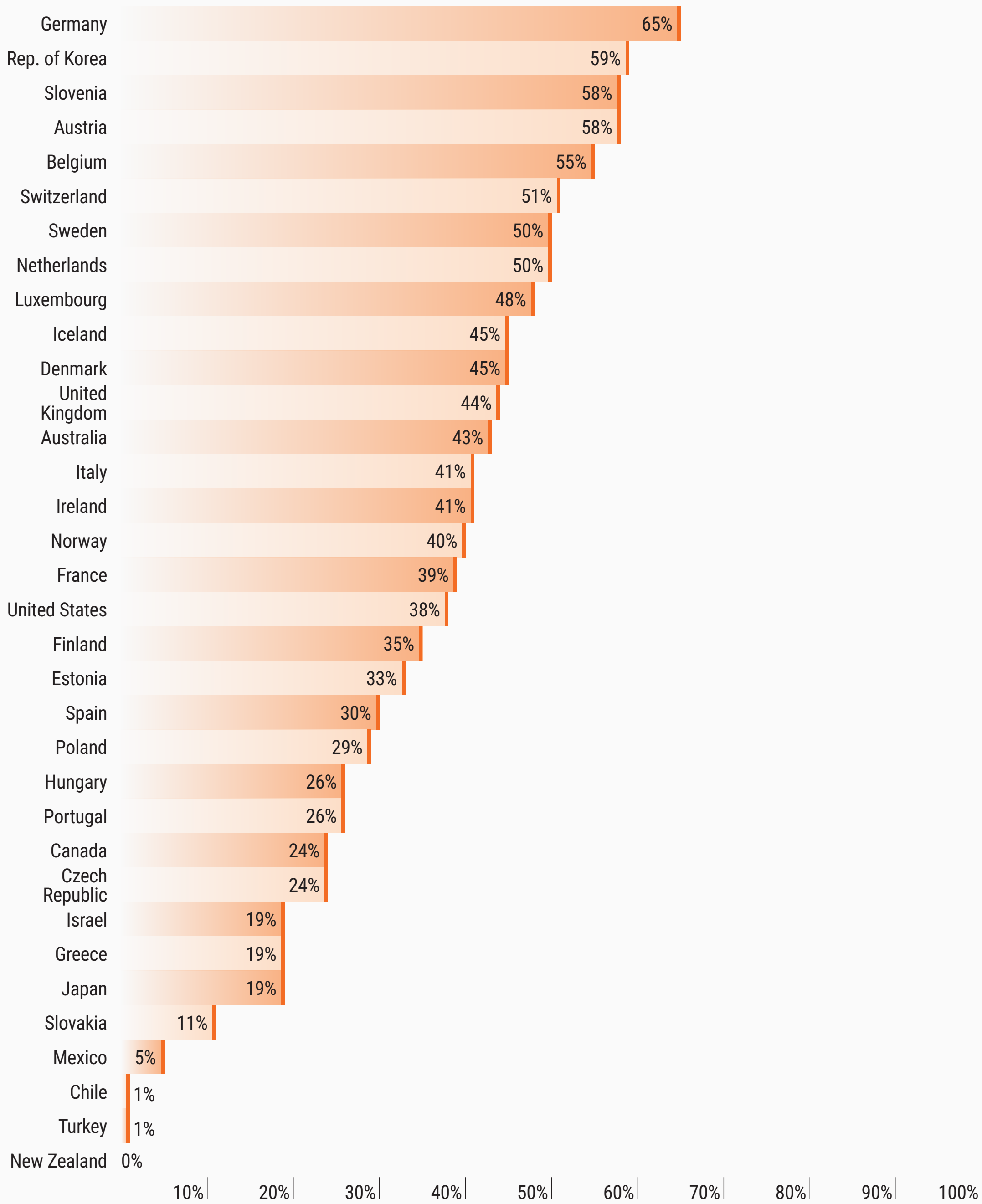


**Figure 5.13** Recycled and composted waste as a share of total municipal waste in OECD countries (per cent), 2013 (adapted from McCarthy 2016)




Germany in 2013 to less than 1 per cent in Turkey, with Estonia and Spain at 33 and 30 per cent (McCarthy 2016) (Figure 5.13).

Waste recycling is increasing in many countries, for example through the growth of waste material separation and accessible municipal recyclable product collection services as well as collection and disposal fees for wastes not recycled. Local and national bans on plastic bags, cups and packaging are another incentive to recycle and reuse. However, separation and collection for recycling only makes economic sense if the material is actually recycled.

The waste industry depends closely on the secondary materials industry to provide the market for recycling. It is estimated that some 700 to 800 million tonnes of "waste" are recycled as "secondary commodities", derived from municipal solid waste and other waste streams. In terms of tonnage, recycling markets are dominated by ferrous scrap (steel) followed by paper and board. In terms of value, steel ranks first while non-ferrous metals such as aluminium and copper rank second. The main traded secondary materials represent around 10-15 per cent of overall world waste generation, excluding construction and demolition, agricultural and forestry, and mining and quarrying wastes (UNEP and ISWA 2015b).

### Informal sector recycling generates significant releases of hazardous substances

Where wastes are exported from wealthy countries for recycling in lower-income countries, the potential for adverse environmental and health exposures is present. In some regions and countries, up to 95 per cent of electronic waste is treated and processed informally and by untrained workers lacking appropriate equipment. This often results in significant releases of chemicals such as heavy metals (lead, cadmium, mercury, etc.), PCBs, brominated flame retardants, PAHs and dioxins and furans to the environment (Annamalai 2015; Heacock *et al.* 2016). Heavy metals and other pollutants are routinely released from e-waste recycling operations to air, water and soil (Awashthi, Zeng and Li 2016; He *et al.* 2017).

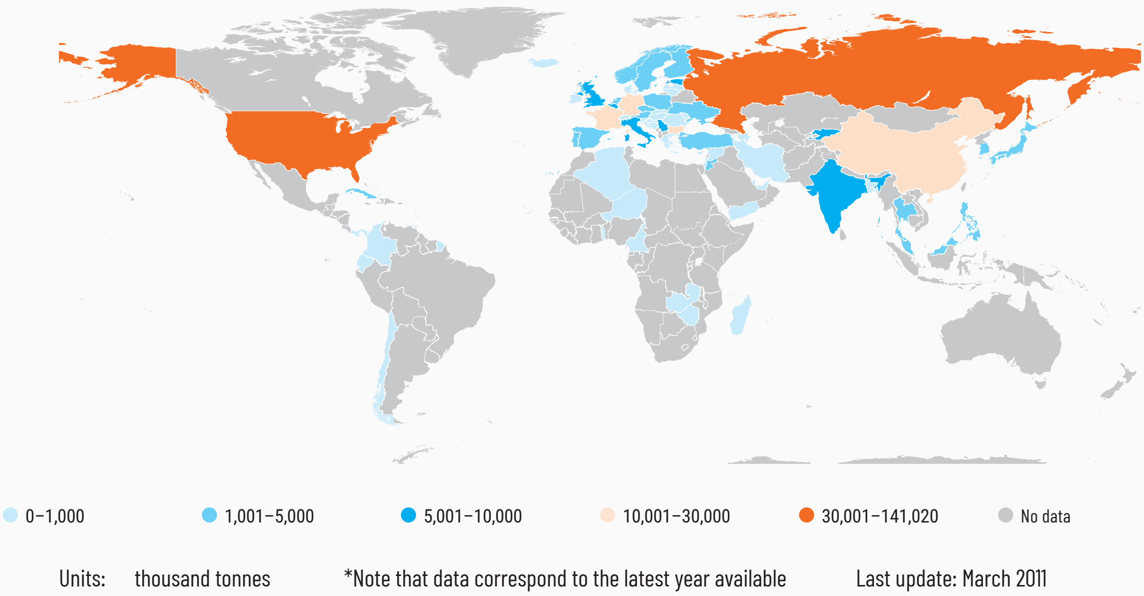
A good example involves lead battery recycling. Non-regulated, informal battery recycling practices occur in many countries and have resulted in lead exposure and poisoning, with young children being particularly at risk (Daniell *et al.* 2015; WHO 2017). Where such recycling is carried out in urban areas with high population densities, large numbers of people may be exposed to high levels of lead.

China recently instituted a series of import restrictions on "foreign wastes" that were previously exported to China for potential treatment and recycling. This ban covers imports of 24 types of materials, including unsorted paper and the low-grade polyethylene terephthalate used in plastic bottles. Before this, China had been processing at least half of the world's exports of waste paper, metals and used plastic (7.3 million tonnes in 2016) (de Freytas-Tamura 2018).

### Hazardous waste is generated worldwide

Data on the generation and management of hazardous waste are lacking or remain weak for many countries. Furthermore, comparisons are difficult when the types of hazardous waste covered and the definitions and methods used differ. Global data on hazardous waste generation are therefore not exhaustive despite the progress made by many countries (UNEP and ISWA 2015a). Figure 5.14 provides a global overview of hazardous waste generation by major country.

**Figure 5.14** Global hazardous waste generation in 2009 (thousand tonnes) (adapted from United Nations Statistics Division 2011)*




Data from the EU PRTR show that the waste and wastewater management sectors account for the largest total transfers of hazardous waste in Europe, followed by the chemical industry and the metal production and processing sector (EEA n.d.). Some 20.3 to 28.8 million tonnes of hazardous waste are reported to be generated every year in the United States, of which 5-10 per cent goes to landfill and some 90- 95 per cent is deep well injected (US EPA 2018). The chemical industry is the largest source of the country's hazardous waste, but much of this waste is treated on-site. The oil, gas and coal industries are the next largest source (UNEP and ISWA 2015a). Figure 5.15 and Figure 5.16 show the sources of hazardous wastes in the United States and the EU.

**Figure 5.15** Sources of hazardous waste in the United States by sector, 2011 (per cent of volume) (adapted from UNEP and ISWA 2015a, p. 93)

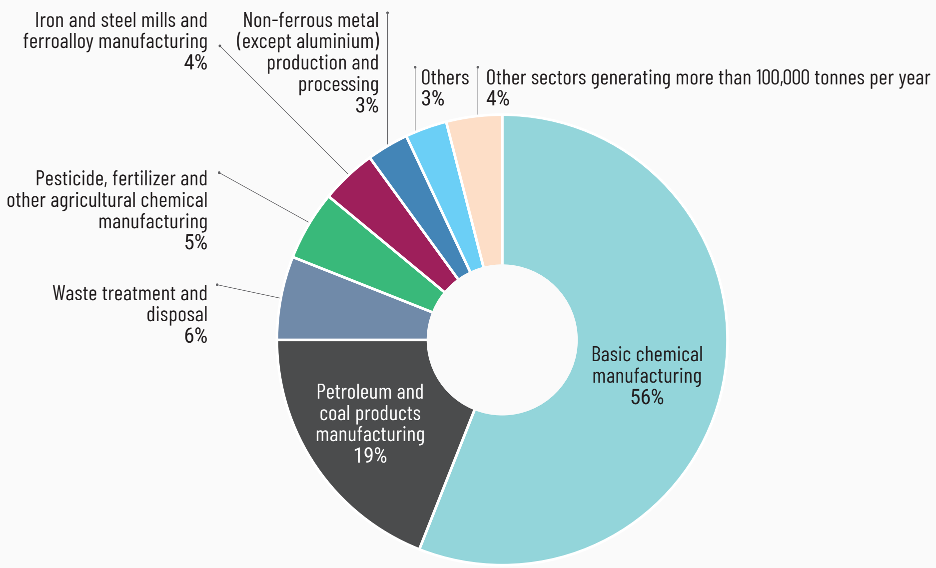
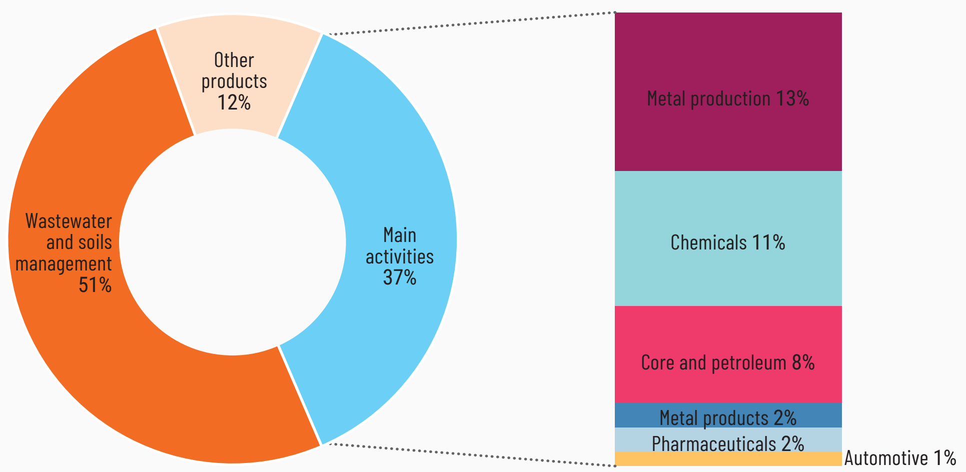


**Figure 5.16** Sources of hazardous waste in EU countries by sector, 2015 (per cent) (adapted from EEA n.d.)




## Regional hazardous waste generation largely reflects the degree of industrialization

Asian countries report that they are generating increasingly large volumes of hazardous waste. The National Bureau of Statistics of China reported that in 2014 China produced 3,256.7 million tonnes of industrial solid waste, including 36.3 million tonnes of hazardous waste (of which 20.6 million tonnes were treated and further used and 9.3 million tonnes were disposed) (National Bureau of Statistics of China 2015). Table 5.2 shows hazardous waste generation data in selected countries that provided updated figures as of September 2016 (Secretariat of the Basel, Rotterdam and Stockholm Conventions [BRS Secretariat] 2016). China reports the generation of the largest volumes of hazardous wastes.

Whatever the region of the world, there is a gap between the generation of hazardous waste and the treatment capacity for the waste and proper information on its chemical composition. As an example, in the EU, where hazardous waste is largely well-handled and treated, the gap between the amounts of hazardous waste generated and treated is 28 per cent (up to 29 million tonnes).

**Table 5.2** Hazardous waste generation in selected countries, 2014 (tonnes) (BRS Secretariat 2016)

| Country | Volume (tonnes) |
|---|---|
| Australia | 10,031,053 |
| Austria | 1,252,125 |
| Bulgaria | 17,792,272 |
| China | 36,335,236 |
| Estonia | 10,484,292 |
| Germany* | 17,000,000 |
| Iran | 1,099,215 |
| Malaysia | 1,665,347 |
| Morocco | 5,900,000 |
| Norway | 1,380,000 |
| Philippines | 1,712,394 |
| Poland | 1,974,866 |
| South Africa | 11,353,856 |

Data rounded to the nearest integer. Many countries provided no data. Data cannot be used to draw conclusions about regional or global patterns, or about countries not listed here.
* Preliminary figure, subject to verification

### Generation of electronic waste is increasing throughout the world

The enormous growth of the electronic technologies of the "Digital Age" has created a significant impact on global waste generation in the form of electronic product waste, or e-waste. Electronic waste often contains toxic chemicals such as mercury, lead and brominated flame retardants, as well as a variety of precious metals and rare materials. Large quantities of this waste are disposed of illegally when electronic waste is transferred within and between countries, misrepresented as second-hand products (Rucevska *et al.* 2015). The unregulated international transfer of hazardous wastes has been reduced since the signing of international agreements such as the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal and the Bamako Convention; however, unregulated electronic waste trade continues across national borders (Obradović *et al.* 2014).

In 2016 the global economy generated some 44.7 million tonnes of e-waste, which is expected to grow to 52.2 million tonnes by 2021. Of the generated waste, approximately 1.7 million tonnes are disposed in municipal waste in higher-income countries and are likely to be incinerated or landfilled. Globally, only 8.9 million tonnes of e-waste are documented to be collected and recycled, corresponding to 20 per cent of all the e-waste generated. In 2016 Asia was the region that generated the largest amount of e-waste (18.2 million tonnes), followed by Europe (12.3 million tonnes), the Americas (11.3 million tonnes), Africa (2.2 million tonnes) and Oceania (0.7 million tonnes) (Baldé *et al.* 2017).

Informal recycling markets in China, India, Pakistan, Viet Nam and the Philippines handle 50-80 per cent of this e-waste. Much of the recycling processes involves shredding, burning and dismantling products, often in "backyards". According to a study carried out in India, over 30,000 computers were estimated to have been decommissioned every year in the city of Bangalore alone. This resulted in waste containing more than 1,000 tonnes of plastics, 300 tonnes of lead, 0.23 tonne of mercury, 43 tonnes of nickel and 350 tonnes of copper (Needhidasan, Samuel and Chidambaram 2014). During the 2000s more than 20 million tonnes of e-waste was recycled per year, mostly within the informal sector in and around Guiyu, China (Rucevska *et al.* 2015). Today much of the most hazardous recycling has been closed at Guiyu and replaced with more regulated operations. However, e-waste recycling in the informal sector still continues in other parts of Asia and Africa.

### Significant amounts of waste are generated in the chemical industry

An analysis shows that the amount of waste generated per kg of chemical product increases up the chemical value chains from oil refining via bulk (basic) chemicals to fine chemicals and pharmaceuticals. In the production of pharmaceuticals, for example, at least 25 kg of emissions and waste (and at times more than 100 kg) are generated for every kg of product, highlighting resource inefficiencies (Sheldon 2017) (Table 5.3).

**Table 5.3** Resource efficiency in the chemical industry: ratio of products and waste generation (Sheldon 2017, p. 19)

| Industry segment | Tonnes per year | e-factor (kg waste per kg product) |
|---|---|---|
| Oil refining | $10^6$-$10^8$ | < 0.1 |
| Bulk chemicals | $10^4$-$10^6$ | < 1-5 |
| Fine chemicals | $10^2$-$10^4$ | 5-50 |
| Pharmaceuticals | 10-$10^3$ | 25- >100 |

The e-factor is a measure to indicate the amount of waste created for each unit of product manufactured. An e-factor of 10 means that 10 kg of waste is generated for 1 kg of product.

## 5.4 Chemical releases: industrial accidents and natural disasters

### 5.4.1 Releases from chemical accidents are significant

Chemical accidents often cause significant impacts on human health and the environment and severely disrupt community and economic life (see also Part III, Ch. 6). The best known example is the exposure of more than half a million people, including thousands fatally, to methyl isocyanate gas released from the Union Carbide pesticide plant in Bhopal, India in 1984 (Broughton 2005).

Accidents at mining sites also cause significant chemical releases to the environment. Tailing ponds often hold large amounts of hazardous chemicals, and the greatest releases occur when dams burst. It is estimated that 3,500 tailings impoundments exist globally, and that every year two to five major failures and 35 minor failures occur (Martin and Davies 2000). The magnitude of such incidents was illustrated in the case of the Baia Mare spill, when some 100,000 $m^3$ of cyanide and other contaminated waste were released into nearby rivers in Romania (Soldán *et al.* 2001). More recently, the catastrophic failure of the Bento Rodrigues iron mine tailings dam in Brazil caused a toxic flow of mud into the Doce River region, killing 19 people and disrupting the livelihoods and adversely affecting livelihoods of more than 1 million people (Fernandes *et al.* 2016). In the same year the fire and explosion of a hazardous goods warehouse at Tianjin Port resulted in the deaths of 165 people and the injury of nearly 800 others. The incident caused euros 1 billion in damages without taking account of the vast economic costs to neighbouring businesses and residents (China State Administration of Work Safety 2016).

Chemical accident trends in emerging economies are difficult to assess because of a lack of data. Some data are available regionally. For example, a recent review of sudden chemical leakage accidents in China identified 666 incidents between 2006 and 2011. Ninety-five per cent of the pollution came from industrial facilities. Petroleum accidents made up the largest number of these incidents, followed by those involving corrosives and ammonia liquids (Li *et al.* 2014). In addition, the Work Accident Map of the China Labour Bulletin shows 42 accidents involving gas or chemical exposure, 33 explosions and 28 fires occurring in workplaces in China in 2017 (China Labour Bulletin 2018). Some accident data are also available regarding specific industries, collected either by government regulators or by industry associations. The EU tracks chemical accidents through its Major Accident Reporting (eMARS) System.

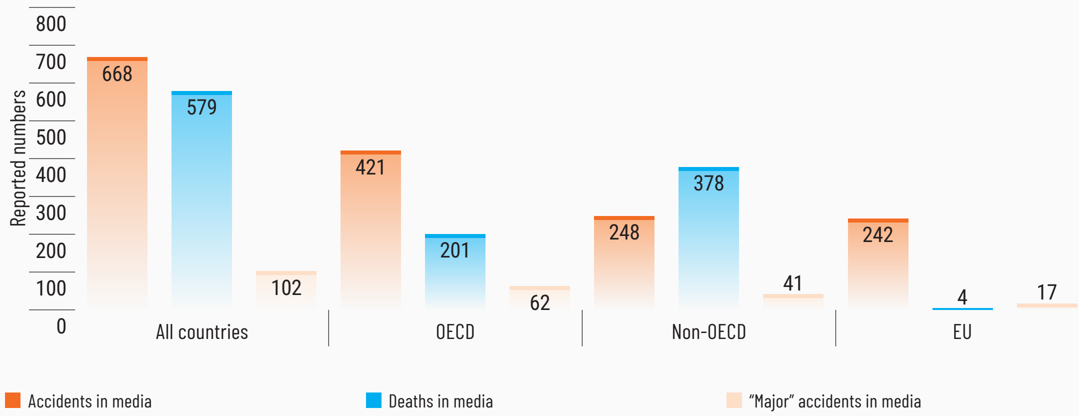
A review of chemical accidents reported in the news media between October 2016 and September 2017 identified 667 facility accidents, with 184 taking place at chemical processing sites (Wood 2017). The great majority of these incidents occurred at fixed facilities (454) and a smaller number during transport (147), followed by pipelines (37) and offshore (9). The study also looked at the differences in incident data between OECD, non-OECD and non-EU countries. The reports indicate that chemical accidents and near misses continue to occur frequently in OECD countries, but have lower fatality rates than those in non-OECD countries. According to the study, OECD countries accounted for nearly two-thirds of events (421 out of 668), but barely one-third of deaths (201 out of 579). The study also looked at reports from EU countries (many of which belong to OECD). Similarly, EU countries accounted for one-third of incidents collected but only four deaths (Figure 5.17).

A similar study of accidents with significant releases to the environment in OECD and EU countries undertaken by the Major Accident Hazards Bureau of the European Commission identified 86 accidents between 1986 and 2013 that resulted in measurable pollution, notably releases to watercourses but also to soil and air (Gyenes and Wood 2014) (Figure 5.18). The majority (30 per cent) of the identified accidents occurred in the chemical industry.

#### Chemical releases are also caused by natural disasters

In a recent report the WHO has drawn attention to chemical releases that may be directly and indirectly triggered by the increasing frequency of

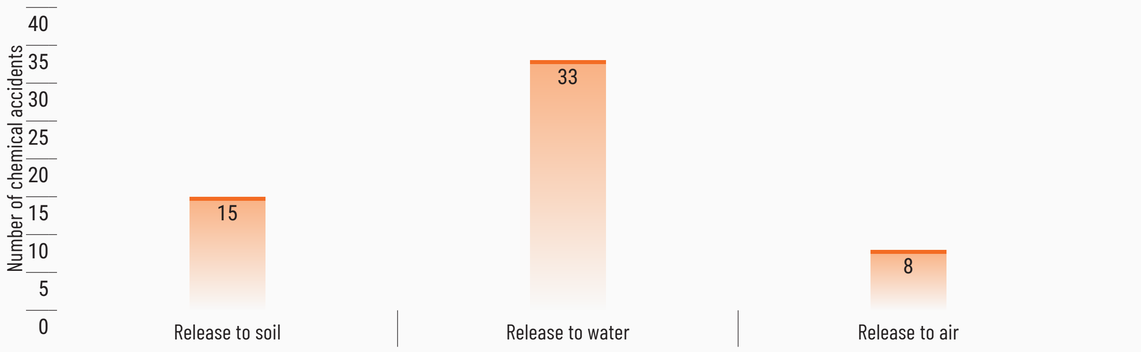
**Figure 5.17** **Chemical accidents reported in news media in OECD, non-OECD and EU countries, October 2016-September 2017 (adapted from Wood 2017, p. 10)**




natural hazards such as earthquakes, hurricanes, tsunamis, floods and forest fires (WHO 2018). Such natural hazards may cause releases of chemicals from damaged fixed chemical installations, oil and gas pipelines, storage sites, transportation links, waste sites and mines (Krausmann *et al.* 2017b).

The recent effects of Hurricane Harvey on petrochemical facilities in Texas in 2017 provides an example. (Griggs *et al.* 2017; Tabuchi and Kaplan 2017; Horney *et al.* 2018) (see also Part III, Ch. 6). In more than a dozen chemical plants and refineries in the Houston area damaged storage tanks, ruptured containment systems and broken pressure relief valves were reported. At least 14 tanks failed when their floating roofs sank under the weight of the heavy rain; others floated or toppled over, tearing flowlines and spewing thousands of barrels of oil and waste water. A

**Figure 5.18** **Number of chemical accidents in OECD countries with significant releases to the environment (adapted from Gyenes and Wood 2014, p. 10)**




spill of almost 11,000 barrels of gasoline into the floodwaters occurred at a storage terminal where tanks had floated and released their content (Texas Commission on Environmental Quality 2017). At a chemical facility fires and explosions occurred when the site lost power and therefore its refrigeration capabilities (Sutherland *et al.* 2018). Benzene, vinyl chloride, butadiene and other known human carcinogens were among the dozens of tonnes of toxic substances released, which polluted the air in the Houston area in the wake of the hurricane (US EPA n.d. c).

Removing wastes after a disaster in a timely and environmentally sound manner is also a significant challenge. These wastes can be highly heterogeneous. They may include not only construction materials (e.g. concrete, steel and timber), but also hazardous substances such as asbestos, pesticides, oils and solvents (Greenwalt *et al.* 2018).

## 5.5 Chemical pollutant and waste data: challenges and opportunities

### Global systems to track and quantify chemical releases to the environment are lacking

There are substantial gaps in data on chemical releases and on global pollution worldwide. Available data concerning chemical releases at the national or regional levels are often inconsistent, incomparable and incomplete, while their availability is regionally varied. Published data are available for a few higher-income countries, but not for most low- and middle-income countries. Consistent data are available across some countries on five to seven priority air pollutants, but not on industrial chemical air emissions or water discharges. Information on the global and regional use and release of pesticides is very limited. Despite efforts to systematically collect information about chemical accidents, a consolidated database does not exist, creating challenges for researchers (Hemmatian *et al.* 2014).

Reporting data on the uses of ozone-depleting chemicals, and modelling data on GHG emissions, provide some broadly accepted global trend metrics. New initiatives such as the Global Mercury Observation System, the Stockholm Convention Global Monitoring Plan and the Global Atmospheric Passive Sampling (GAPS) for monitoring and modelling mercury, POPs and other pollutant concentrations offer useful indications of releases. These systems could provide models for tracking programmes that cover releases of chemicals in pesticides, fertilizers and other manufactured products at the global level. There is a growing literature on the global mass flows of materials and releases of some chemicals, such as perfluorinated and brominated compounds that rely on analytical models. These are also promising.

In some countries PRTRs provide reliable data on chemical releases. However, there is no common list of chemicals, thresholds for reporting, or units by which the data can be aggregated or made available to the public. There is a significant opportunity to create a global PRTR, or an internationally harmonized network of national PRTRs.

## Opportunities exist to improve global waste generation and treatment data

Solid and hazardous waste data are collected by various national governments, and some shipments are reported under international agreements. However, these data are limited due to variations in terms, classification categories and data collection methods. The *Global Waste Management Outlook* (UNEP and ISWA 2015b) and the World Bank's *What a Waste* and *What a Waste 2.0* reports (Hoornweg and Bhada-Tata 2012; Kaza *et al.* 2018) chart comprehensive directions for assessing global solid waste generation, but also admit to the data collection limits raised by inconsistencies in waste definitions, metrics for measurement, and reporting procedures. Collecting data on hazardous wastes is even more difficult. There are no international surveys. Under national reporting obligations, Basel Convention data cover hazardous waste trade. Providing total amounts for hazardous waste generation is optional. National reporting on hazardous waste generation varies by country and is often incomplete (see Part II, Ch. 2).

## More Information is needed on chemicals in products

Product labelling and safety data sheets have increased the amount of information available on the chemical ingredients of formulated products. However, UN Environment's Chemicals in Products Programme has revealed that this information is often incomplete, particularly for low-volume chemicals and unintended contaminants (UNEP 2015). Information is seldom available on the chemical make-up of articles. While there are new models for predicting releases from products, there is no public information on chemical releases, and little global information on the number and volume of products on regional or global markets. More national or international product registries could provide repositories for such information.

# 6/ Concentrations of chemicals in the environment and humans

## Chapter Highlights

A broad range of chemical pollutants are widely found in air, soils, sediments, oceans, freshwater bodies, biota and humans throughout the world.

Concentrations vary widely according to substance, region and environmental media.

Available data indicate positive trends in reducing concentrations of chemicals regulated or restricted by governments (e.g. lead) and multilateral treaties (e.g. some POPs and mercury).

Concentrations of other hazardous chemicals have been identified in various media and are in many cases increasing.

Several chemicals which have long been banned are present in the remotest regions of the world.

Plastic particles are found in water bodies, soils, air and human faeces.

Chemicals of concern concentrate inside buildings and jeopardize indoor air quality.

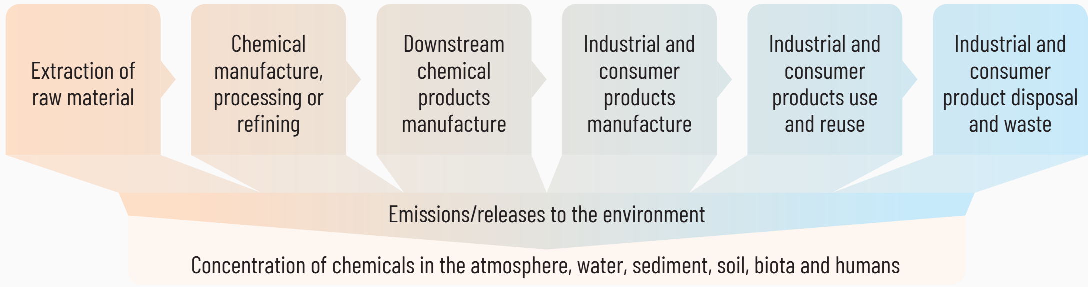
Following the discussion of chemical pollution, this chapter seeks to compile existing data and knowledge on concentrations of chemicals in the environment and humans. It begins with a brief discussion exploring the interface between releases, exposure and concentrations. The remainder of the chapter is structured according to the respective media, beginning with environmental media, then proceeding with biota and concluding with humans. Releases of chemical pollutants from products, production processes and wastes have resulted in a global environment where an increasing number of hazardous chemicals – including lead, bisphenol A, bisphenol S, brominated flame retardants and per and poly-fluorinated compounds – are nearly ubiquitous (Wu *et al.* 2018). Frequently, however, limited data make it difficult to identify trends.

## 6.1 The interface of releases, exposures and concentrations

### Chemicals in the environment: fate and exposures

Once manufactured chemicals are released to the environment, their fate is determined by their molecular properties and the biochemical and physicochemical properties of the receiving medium. "Fate" refers to the transformation processes, as chemicals transfer across different indoor and outdoor environmental media and build up in chemical concentrations in humans and the environment. Chemicals often transfer from one environmental medium to others for which they have a greater affinity and travel long distances through these media. The potential for human exposure to these chemicals is

**Figure 6.1** Value chain of the chemical industry, showing emissions and concentrations




determined by the proximity, frequency and duration of contacts between the chemicals and susceptible populations. It may involve different doses taken in through various exposure routes. Exposures can occur throughout a chemical's life cycle, from its original extraction or production, through its processing and integration into a product, during product distribution and use, and on to its ultimate disposal (Figure 6.1).

## Concentrations around point source releases vs. long-range transport of chemicals

Chemical pollutants may concentrate in air, surface and groundwater, soils and sediments, and living organisms (including people). These concentrations tend to be higher near the point of release and to decrease with distance, owing to

dilution, chemical transformations, and microbial or chemical degradation.

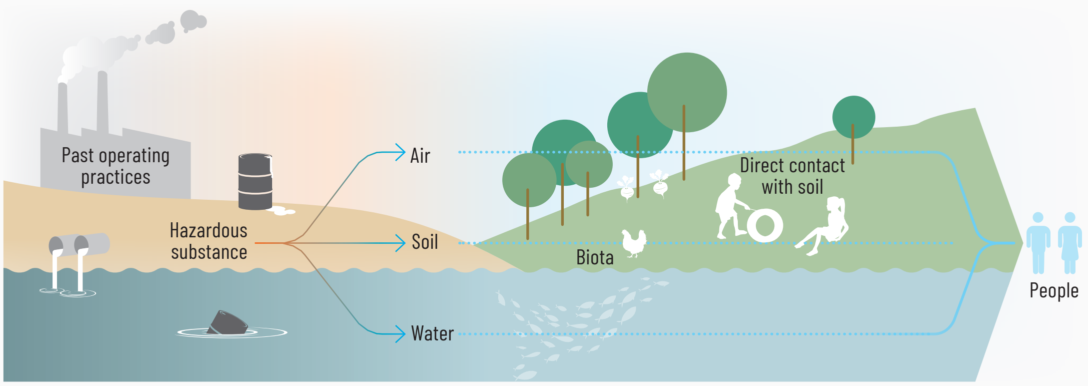
Persistence is a key determinant of fate, with substantial variations in the environmental elimination half-lives of chemicals, which range from a few minutes to hundreds of years. Long-range transport of chemicals via atmospheric or surface water currents may distribute persistent chemicals far from the originating source. The transport of chemical-intensive products internationally provides a new and relatively unstudied way in which manufactured chemicals are distributed throughout the global environment. Manufactured chemicals may be found in physical and ecological niches such as polar regions, where air, river and ocean currents, drifting sea ice and migrating wildlife transport these chemicals long distances and where their degradation is restricted (Beyer *et al.* 2000).

## The potential effects of bioaccumulation on chemical intake

People are exposed to manufactured chemicals either directly from products or indirectly through releases to the environment. Exposure routes include ingestion, inhalation, dermal uptake and injection (the latter usually in the case of pharmaceutical products). Ingestion occurs through multiple exposure pathways (e.g. directly though drinking water, eating food or sucking on objects) or indirectly through swallowing dust (Figure 6.2).

Food intake is a major source of chemical exposure. The magnitude of exposure from food depends on the amount of the chemicals and their persistence and/or their bioaccumulative potential. Fat soluble, lipophilic chemicals tend to accumulate in fish, meat or dairy products and

**Figure 6.2** **Exposure pathways**




**Box 6.1** **Bioaccumulation and biomagnification (Naik 2018)**

Bioaccumulation and biomagnification often occur in conjunction with each other.

- *Bioaccumulation* is the process by which chemical toxicants build up in individual organisms.
- *Biomagnification* is the process by which chemical toxicants pass from one trophic level to the next and, in doing so, increase in concentration in higher-level trophic organisms.

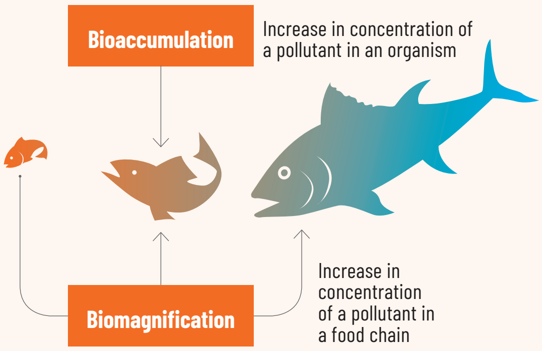
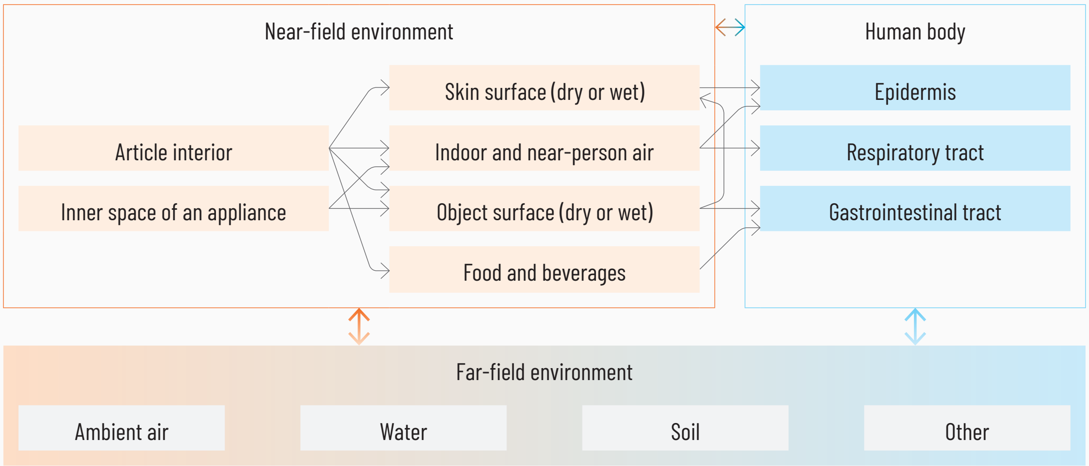


**Figure 6.3** Links between the near-field environment and compartment of entry, the far-field environment, and the human body (adapted from Huang *et al.* 2017, p. 185)




Reprinted with permission from Elsevier

to biomagnify throughout the food web; their concentrations can be up to a million times higher in fish than in the fish's water habitat (Arnot and Gobas 2006). Lipophilic chemicals also tend to be persistent and to have long half-lives and thus contribute to high internal exposures in humans. Non-bioaccumulating chemicals such as certain phthalates (Ferguson *et al.* 2017), parabens (Fisher *et al.* 2017) and triclosan (Weiss *et al.* 2015) can be identified in biomarker sampling studies where exposures may be continuous (Box 6.1).

### Exposures to consumer products can increase chemical concentrations in people

For many people in higher-income countries (and some in middle- and lower-income countries) the most significant exposures to hazardous chemicals may come from consumer products. Since the frequency of consumer contact with products and the exposure duration are often high (Wambaugh *et al.* 2013), these exposures can result in significant chemical concentrations in human bodies, especially during pregnancy (Lang *et al.* 2016). Exposure depends not only on chemical properties, but also on how the product is used and the manner in which the body is exposed (Huang *et al.* 2017) (Figure 6.3).

### A number of chemicals of concern are found in food products

Food is a particularly significant vehicle for chemical exposure. Sampling data compiled by the WHO (2018a) on food contaminants include lead in wine at up to 584 micrograms/kilogram (μg/kg), dioxins in cooked crabs at 740 picograms/kilogram (pg/kg), and the neonicotinoid imidacloprid in lettuce at 10,790 μg/kg. A study of common foods in the United States (Liao and Kannan 2013) found several bisphenols contaminants in 75 per cent of analyzed food samples. Plastic particles have been found in salt, beer and honey (Hartmann 2018; Kosuth, Mason and Wattenberg 2018), soft drinks (Qunitili 2018), and bottled and tap water (Kosuth, Mason and Wattenberg 2018; Mason, Welch and Nertko 2018) as well as in human faeces (Eurekalert 2018; Parker 2018; Schwab *et al.* 2018). Contaminants have also been found in baby and infant food. For example, a 2017 study found methylmercury and inorganic arsenic in rice baby foods (Rothenberg *et al.* 2017).

Pesticides may be present in food in various concentrations. A recent study of honey collected across the world found evidence of neonicotinoids in most samples. (Mitchell *et al.* 2017). A 2019

compilation of United States Department of Agriculture and United States Food and Drug Administration data (Environmental Working Group [EWG] 2019) found that almost 70 per cent of produce sold in the that country contained pesticide residues and that there were "225 different pesticides and pesticide breakdown products on popular fruits and vegetables". However, most of these were at "very low levels" (Bernhardt *et al.* 2019). The data set includes, for example, kale contaminated with Dacthal, classified by the US EPA as a possible human carcinogen (US EPA 2018). Compiling data on the analysis of 85,000 samples for 791 pesticides, the European Food Safety Authority (EFSA) concluded that more than 96 per cent of the tested samples fell within the legal limits, a slight decrease compared to the previous reporting year (EFSA 2018). This 2016 report further notes that more than 50 per cent of the tested samples were free of quantifiable residues. While 2.4 per cent of the samples from EU and European Economic Area (EEA) countries were above legal limits, 7.2 per cent of the samples from non-EU countries exceeded legal limits. Data availability for developing countries is limited, but limited management, surveillance and regulatory capacity is likely to cause more concerns. For example, a study sampling foods purchased at a local market in Bolivia found pesticide residues in 20 per cent of lettuce samples to be above the maximum residue limits. The study also observed that "no samples contained concentrations of pesticides which alone or together would lead to exposures that exceeded the acceptable daily intake or the acute reference dose" (Skovgaard *et al.* 2017).

## Highly exposed and susceptible populations

Depending on the dominant exposure pathways, different subpopulations are exposed to hazardous chemicals in different ways (Hunt *et al.* 2016; UNEP 2016a; Secretariat of the Strategic Approach to Chemicals Management [SAICM Secretariat] 2018; Undeman *et al.* 2018). In the case of exposure to PCBs contained in fish, subsistence fishermen and high-end fish consumers are among those most highly exposed (United States Agency for Toxic Substances and Disease Registry [US ATSDR] 2014). In the case of dermal uptake of parabens, frequent


consumers of personal care products will have higher exposure levels. Children can be exposed through direct contact with chemicals in various articles (e.g. phthalate plasticizers via mouthing, swallowing dust or direct contact) (Dewalque *et al.* 2014; Guo, Wang and Kannan 2014). Workers can be highly exposed to chemicals in their work environments and to chemicals used in product manufacturing (Kijko *et al.* 2015), especially where protective measures are limited (Arastoo *et al.* 2015). The burden of direct workplace exposure to hazardous chemicals is often unevenly distributed between women and men, who have different sensibilities to these chemicals, play different gender roles and may be exposed in different ways (UNEP 2016a; Women in Europe for a Common Future [WECF] 2016).

Generic and multi-media models are available to predict chemical fate and exposure. Results from these models help predict the distribution of environmental concentrations for a wide range of substances (and the proportion of human intake via multiple pathways) (MacLeod *et al.* 2011; Webster *et al.* 2016; Wannaz, Fantke and Jolliet 2018; Wannaz *et al.* 2018). More recently, new approaches have become available to evaluate exposure to a wide range of chemical-product combinations, accounting for both environmental and indoor exposures (Isaacs *et al.* 2014; Fantke *et al.* 2016). However, further research is needed to better understand and quantify product-specific exposure pathways such as dust, gaseous dermal uptake, and direct contact with textiles and other articles.

## 6.2 Concentrations in environmental media

Concentrations of manufactured chemicals in the environment are found around the world. Much of these concentrations come directly from industrial facility releases, or municipal landfill leakage, air deposition, contaminated water run-off, land applications of pesticides and fertilizers, and commercial products. However some also come from complex chemical transformations in environmental media. Global, regional and local monitoring studies reveal both increasing and decreasing trends.

### 6.2.1 Air

#### Concentrations of priority air pollutants are decreasing in some regions

Air concentrations of most priority air pollutants arising from combustion sources in higher-income countries are on a long-term decline. In the past two decades sulphur dioxide concentrations in North America and Europe have fallen by more than two-thirds because of improved energy efficiencies, shifts in fuel mixes, and widespread application of end-of-pipe desulphurization in the power sector (EEA 2015; US EPA n.d.). Average air concentrations of lead in air have decreased in regions where government regulations have restricted lead additives in fuel. In the United States, for example, airborne lead concentrations declined 92 per cent between 1980 and 2013, largely due to reduced lead content in gasoline (US EPA 2014; US EPA 2017a). Furthermore, Canada implemented the Air Quality Management System, which is a comprehensive and collaborative approach by all levels of government to reduce the emissions and ambient concentrations of various pollutants of concern (air pollutants that case smog and acid rain). These reductions have contributed to the reduction of the air pollutants that Canadians breathe every day (Canadian Council of Ministers and of the Environment 2014).

#### However, concentrations of the same air pollutants are increasing in lower-income countries

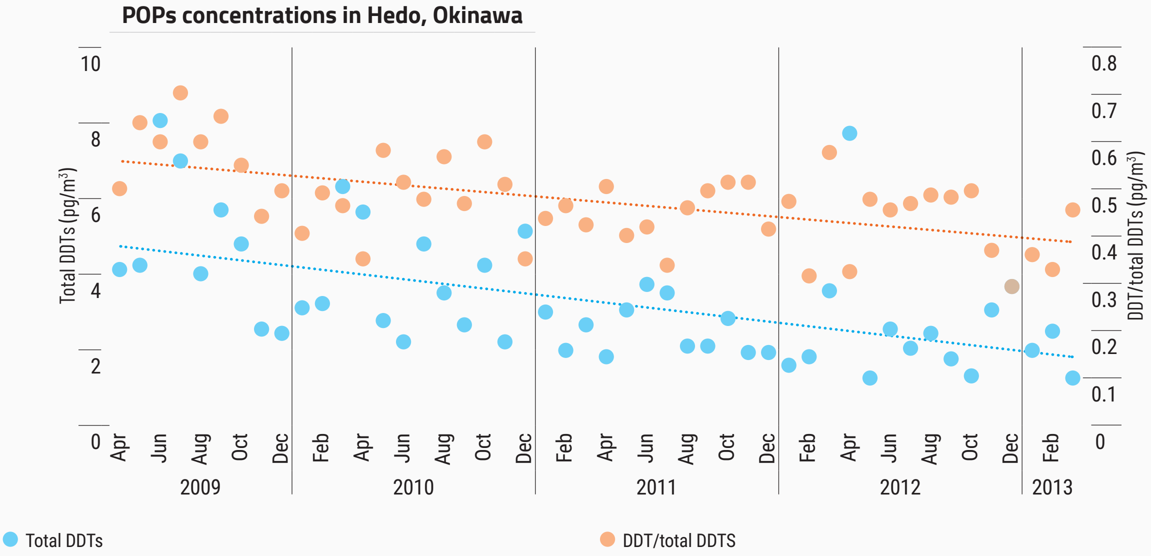
The WHO estimates that around 90 per cent of people worldwide breathe polluted air with an annual mean value of particulate pollution higher than the WHO air quality guideline levels (WHO 2018b). The highest ambient air pollution levels are in the Eastern Mediterranean region and Southeast Asia. Particulate pollution levels in low- and middle-income cities in Africa and the Western Pacific are also high. In a WHO survey of 795 cities in 67 countries, 98 per cent of cities with more than 100,000 inhabitants in lower- and middle-income countries did not meet WHO air quality guidelines. The main sources of particulate matter (PM) air pollution include cooking (the principal source of household air pollution), industry, agriculture, transport and coal-fired power plants (WHO 2018c).

#### Some studies show concentrations of certain persistent organic pollutants in the atmosphere are declining in some regions

The second *Global Monitoring Report* of the Global Monitoring Plan for Persistent Organic Pollutants (POPs) under the Stockholm Convention concludes that concentrations of listed POPs in air have largely decreased, and that concentrations

© UNEP/Victor Estellano, passive air sampling

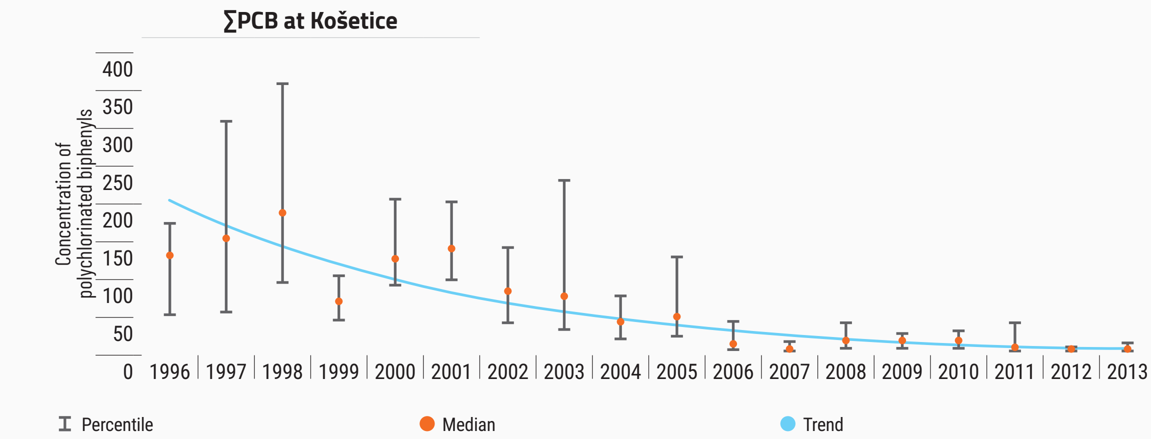
**Figure 6.4** **Trends in DDT concentrations in air, and ratios between DDT and total DDTs (pg/m³), in Hedo, Japan, 2009-2013 (adapted from Nagai *et al.* 2015, p. 41)**




Air monitoring undertaken at a site in Japan between 2009 and 2012 showed deceasing concentrations for total DDT (sum of six isomers, including the major breakdown products of DDT) as well as for the ratios of DDT (sum of p,p'- and o,p'-DDT, the major components of commercial DDT) and total DDT, which suggests a reduction in DDT input during the sampling period.

of so-called "legacy POPs" (organochlorine pesticides, PCBs and PCDD/PCDF) have decreased strongest since the 1980s (Šebková *et al.* 2014). Figure 6.4 and Figure 6.5 show trends in PCBs and dichlorodiphenyltrichloroethanes (DDTs) concentrations at two sites: Košetice in the Czech Republic and Hedo in Japan. Concentrations of chemicals more recently listed in the Stockholm

**Figure 6.5** **Trends in concentrations of PCBs in Košetice, Czech Republic (pg/m³), 1996-2013 (adapted from Šebková *et al.* 2014, p. 61)**




Over a period of 18 years, concentrations of sum PCBs gathered through active sampling showed decreasing trends at a station in the Czech Republic, pointing towards the effectiveness of national and international action taken on PCBs, including through the Stockholm Convention.

Convention as POPs (e.g. PBDEs, PFOS, HBCD and PeCBz) increased through the 1990s, subsequently stabilized, and then started to decrease in the early 2000s.

Atmospheric concentrations of PCBs, DDT, chlordanes, and polybrominated diphenyl ether (PBDE) congeners (such as BDE-209) are slowly declining in Arctic air. Atmospheric monitoring in other regions of the world has revealed that, among all POPs, pesticides were found at the highest concentrations in Africa and in Latin America and the Caribbean. Specifically, concentrations of DDTs, hexachlorocyclohexane (HCH) and endosulfan were dominant in Africa while lindane was detected at the highest concentrations in Latin America and the Caribbean. These concentrations were all decreasing in the Asia-Pacific region, Central and Eastern Europe and Western Europe (UNEP and Secretariat of the Stockholm Convention 2017).

### Concentrations of some flame retardants are decreasing, but those of others are increasing

A recent study analyzing air monitoring data in the Great Lakes Basin in Canada found that PBDE concentrations had declined between 2005 and 2014 (Shunthirasingham *et al.* 2018). While these PBDE concentrations show declining trends, concentrations of other flame retardants present increasing concerns. Data from the Global Atmospheric Passive Sampling (GAPS) Network suggest that concentrations of atmospheric PBDEs are similar across regions, although lower concentrations are observed in Latin America and the Caribbean in comparison to North America and the Asia-Pacific region. These differences may be due to the influence of local sources, as well as historically higher usage of PBDEs in North America (UNEP and Secretariat of the Stockholm Convention 2017; Rauert *et al.* 2018). Minimal differences in concentrations were identified across urban, agricultural and polar regions for PBDEs, and for their POPs-like flame retardant replacements, organophosphate esters (OPEs) and other more recently introduced flame retardants (Rauert *et al.* 2018). Despite positive declining trends for PBDEs across the globe, monitoring in the Arctic has revealed uncertain trends for other flame-retardant chemicals (Figure 6.6).

In some studies elevated concentrations of chlorinated flame retardants in the Arctic are now being detected which are comparable to those found in urban air, while organophosphate-based flame retardants (PFRs) are being detected at higher concentrations than PBDEs. Moreover, air concentrations of chlorinated PFRs are commonly reported at concentrations higher than those of other classes of flame retardants in the same samples, often 100 times higher (AMAP 2017).

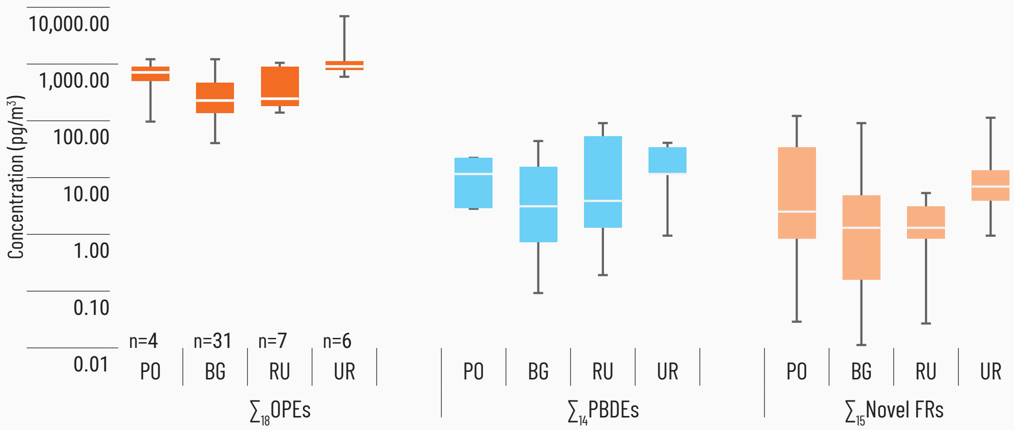
### Atmospheric concentrations of mercury are still of concern

It is estimated that over the past century anthropogenic activities cumulatively have increased atmospheric mercury concentrations by 300-500 per cent. There is a clear gradient in concentrations of mercury in air driven by local and regional sources, with higher concentrations in the northern hemisphere compared to the southern hemisphere. Most monitoring sites in the northern hemisphere show a downward trend in mercury concentrations between 2007 and 2014, while sites in South Africa show a slight increase. In North America and Europe, concentrations in air declined 10-40 per cent between 1990 and 2010 and have more recently plateaued. In the Arctic, concentrations have also been declining, although at a slower rate than elsewhere possibly due to mercury released during permafrost melt from climate change. (Schuster *et al.* 2018). Atmospheric mercury concentrations at remote sites in China are elevated compared to those at remote sites in Europe, North America and other locations in the northern hemisphere. It is assumed that regional anthropogenic emissions and long-range transport of mercury are driving these elevated mercury concentrations (UNEP and AMAP 2018).

### Chemicals concentrate inside buildings, affecting indoor air quality

Manufactured chemicals released from building materials, home and workplace furnishings, and

**Figure 6.6** **Global atmospheric concentrations of polybrominated diphenyl ethers (PBDEs) and of organophosphate esters (OPEs) and other novel flame retardants (FRs) at four location types: polar, background, rural and urban, 2014 (adapted from Rauert *et al.* 2018, p. 2778)**




Analysis of passive air samples from the Global Atmospheric Passive Sampling Network suggested that "global atmospheric concentrations of PBDEs have not declined since regulatory measures were implemented" (Rauert *et al*. 2018). The study found organophosphate esters in concentrations at least an order of magnitude above those detected for PBDEs.

household and personal care products can result in higher concentrations inside residential and workplace facilities than outside (EEA 2016). New buildings or recently redecorated environments, where the frequency of air exchanges has been reduced, have been associated with high concentrations of these chemicals in household and interior dusts (Mercier *et al.* 2011).

A recent study of concentrations of chemicals – including phthalates, flame retardants, chlorinated solvents and others – in new and recently renovated housing found indoor air concentrations exceeding available risk-based screening levels in all sampled homes for at least one of the targeted chemicals (Dodson *et al.* 2017). This study not only identified chemicals from building materials (e.g. certain flame retardants), but also chemicals used in personal care products such as dibutal phthalate (DBP). A recent review of semi-volatile organic compounds (SVOCs) in indoor air found significant concentrations in residences, schools and office buildings at sites throughout the world (Lucattini *et al.* 2018). Another study analyzing concentrations of volatile organic compounds (VOCs) in newly renovated residences in Shanghai found a dozen VOCs classified by the International Agency for Research on Cancer as confirmed or probable carcinogens in more than 60 per cent of samples (Dai *et al.* 2017).

Indoor dust is a reservoir for chemicals released from commercial consumer products. Heavy metals such as lead and cadmium have been identified in household dust. Lead is a common constituent in dust from older homes in India where lead paint may still be present (Kumar and Scott 2009). The Canadian House Dust Study found elevated concentrations of lead in dust samples from Canadian homes in central urban areas (Rasmussen *et al.* 2011). Permethrin and cypermethrin were the most common pesticides identified in a review of 15 published studies of floor wipes and dusts in residential environments in the United States (Morgan 2012). A recent study of indoor dust samples taken from residential settings in the United States identified chemicals of recognized health concern. Phthalates occurred in the highest concentrations, followed by phenols, chemicals used to replace regulated flame retardants, fragrances and PFASs (Mitro *et al.* 2016)

### 6.2.2 Freshwater and oceans

Continuous discharges of hazardous chemicals into freshwater bodies and oceans, atmospheric


deposition, and the dynamic nature of water cycles results in the presence of chemical contaminants in rivers, streams, lakes, reservoirs, groundwater and oceans.

## Globally, clean drinking water is available to most people but not all

The WHO has reported that 91 per cent of the world population has access to clean drinking water. However, some 660 million people remain without safe water while chemical contamination from pesticides, landfill leachate and industrial discharges continues to be a local problem in low- and middle-income countries (United Nations International Children's Emergency Fund and WHO 2015). Although over 200 chemicals in drinking water are regulated by some governments, there is growing public concern about the presence of chemicals such as perfluorinated compounds, dioxane, siloxanes, pharmaceuticals, perchlorate, musks, illicit drugs, pesticide degradation products and sunscreens (Villanueva *et al.* 2013).

## Chemical pollutants occur in freshwater bodies throughout the world

A recent analysis of over 800 scientific studies on 28 common insecticide compounds in surface waters in 73 countries found that of the 8,186 insecticide concentrations detected, over 68 per cent were above regulatory thresholds, sometimes by as much as 10,000 times (Stehle and Schulz 2015). A review (Lapworth *et al.* 2012) of the sources of emerging organic contaminants, such as pharmaceuticals, personal care products and selected industrial compounds, in groundwater found microgram-level concentrations of a large range of these contaminants (Lapworth *et al.* 2012). Glaciers also carry pollutants: a recent study (Ferrario *et al.* 2017) determined the occurrence of various POPs (including DDTs and PCBs), pesticides and other contaminants in Alpine glaciers. Certain organochlorine pesticides regulated under the Stockholm Convention have also been found in the Himalayan glaciers (Li *et al.* 2017a).

European water monitoring studies have found that river basins in northern Europe pose higher chemical risks than in the south. Of the 223 chemicals included in monitoring efforts, pesticides, tributyltin, PAHs and brominated flame retardants were the major contributors to chemical risk (Malaj *et al.* 2014). A recent survey of river water samples in 41 cities in 15 countries found detectable concentrations of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in nearly every region studied (Kunacheva *et al.* 2012). In addition to river contamination, many

### Box 6.2 Concentrations of legacy chemicals in water bodies: the Mariana and Kermadec trenches and Lake Geneva

Certain hazardous chemicals whose production and use were banned years ago may still be found at high concentrations in the environment. A recent study (Jamieson *et al.* 2017) analyzed small animals (called amphipods) captured from some of the deepest ocean trenches – the Mariana and Kermadec trenches of the Pacific Ocean – at a depth of more than 10 km. The PCB and PBDE concentrations tested in the animals were at "extraordinary levels", higher than those of animals living in in highly polluted rivers in industrialized regions. This can be explained by the high persistence and accumulation of POPs in fat. In another study (Filella and Turner 2018) several thousand samples of diverse plastic litter of various sizes, age and composition were collected from shores around Lake Geneva in Switzerland. The researchers found a number of banned/restricted hazardous chemicals, including cadmium, mercury, lead and bromium (most likely from brominated flame retardants).

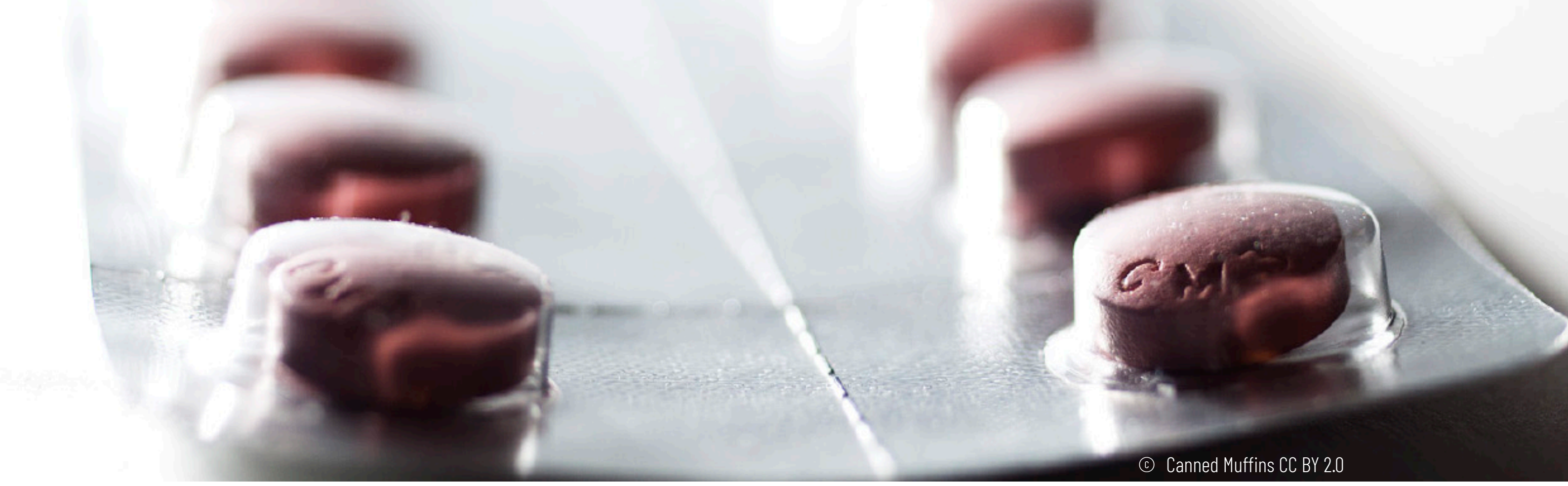

studies in Western Europe and the Asia-Pacific region report concentrations of PFOS in lakes/reservoirs, estuaries and coastal waters (UNEP and Secretariat of the Stockholm Convention 2017) (Box 6.2). A study reviewing available literature and databases on concentrations of chemicals in rivers in the United Kingdom found evidence for the presence of a large variety of hazardous chemicals, including a range of heavy metals, triclosan and lindane. The highest median river water concentrations in order of magnitude were detected for iron, aluminium, zinc and manganese (Donnachie *et al.* 2014).

#### Climate change may significantly increase concentrations of POPs in ocean water

It is anticipated that climate change will alter concentrations of POPs. With the melting of Arctic sea ice, previous reservoirs for POPs are expected to release these chemicals back to the environment. Modelling of future POPs concentrations suggests that ocean waters could be particularly impacted, with up to a four-fold increase in concentrations of some POPs even after their production and use have been phased out (Wöhrnschimmel *et al.* 2013).

#### Pharmaceuticals are found in water across the world

Pharmaceuticals and their metabolites are released to the environment from a variety of sources, including medicinal drugs and agricultural feedlots. A study of 203 pharmaceuticals across 41 countries showed that pharmaceutical residues are present at significant levels in surface and tap water in many countries and regions (Hughes *et al.* 2013). Another study, by the German Environment Agency (UBA), found that in 71 countries in all regions there were more than 600 active pharmaceutical substances or their metabolites and transformation products in surface water, groundwater, tap water and/or drinking water and other environmental matrices (Figure 6.7). Seventeen pharmaceuticals were found in all five United Nations regions, including the anti-inflammatory drug diclofenac (which was detected in 50 countries) (Weber *et al.* 2014; UBA n.d.).

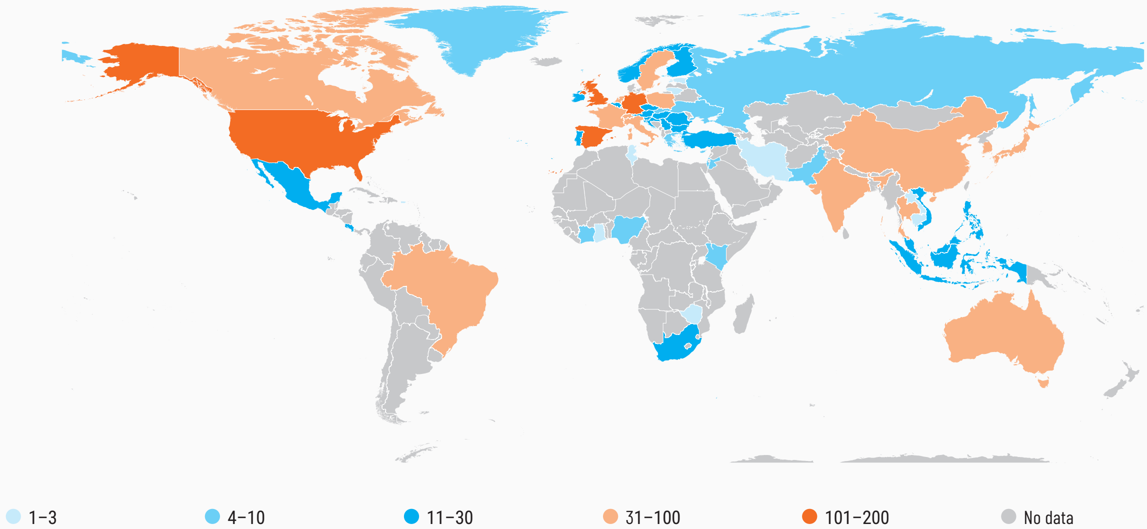



## A wide range of chemical contaminants are present in oceans

A recent review of studies of chemical contaminants in marine environments identified 276 manufactured chemicals, including nine metals/metalloids, 10 organometallic compounds, 24 inorganic compounds, 204 organic compounds and 19 radionuclides. The source of these chemicals ranged from oil and gas operations, and shipping and marine aquaculture, to accidental spills and on-shore discharges (Tornero and Hanke 2016). An analysis (Ho *et al.* 2016) of organotin contamination in the marine environment of Hong Kong in the period 1990-2015 found that, in some cases, there were increasing concentrations of several organotins. Another study (Liao and Kannan 2018) found elevated concentrations of parabens in China's Bohai Sea, with gradual increases documented between 2006 and 2012.

Of the anthropogenic emissions of mercury that have accumulated over the centuries, 50 per cent remains in the oceans, of which 36 per cent is in sea water (Zhang *et al.* 2014). One study suggests that concentrations of mercury in the surface layer of the ocean have doubled over the last 100 years, increasing by 25 per cent in intermediate waters and 10 per cent in deep waters. This variation is likely due to the time it takes surface waters to circulate to the depths (UNEP 2013). Mercury concentrations appear to have increased at depths between 200 and 1,000 metres in the North Pacific Ocean over the last few decades and to have decreased In the North Atlantic. The Mediterranean Sea, in contrast, showed a decrease in mercury concentrations between 1990 and 2004 (UNEP 2013).

**Figure 6.7** **Number of pharmaceuticals detected in surface water, groundwater, tap water and/or drinking water (adapted from Weber *et al.* 2014, p. 6)**



### Ocean and freshwater body sediments store and concentrate chemicals

Studies show that concentrations of currently used brominated flame retardants are increasing in freshwater sediments. Samples drawn from the Great Lakes in North America found that the sediment concentration of decabromodiphenyl ethane (DBDPE) doubles every three to five years in Lake Michigan, and approximately every seven years in Lake Ontario (Yang *et al.* 2012). Sediments in the Adriatic Sea that were deposited within the last two decades represent a 40-80 per cent reduction in peak levels of PCBs, corresponding to national production bans on PCBs in late 1970s (Combi *et al.* 2016).

### An increasing amount of plastic particles is widely found in the world's rivers, lakes and oceans

Microplastics have been found in freshwater bodies, including rivers (Moore *et al.* 2011) and lakes (Eriksen *et al.* 2013). Concentrations in rivers vary significantly, depending on factors such as river basin population densities (Lebreton *et al.* 2017). It has been estimated that some 80 per cent of anthropogenic litter along the shorelines of the Laurentian Great Lakes is comprised of plastics (Driedger *et al.* 2015).

Floating plastic debris, including microplastics, has been reported in the gyres of the North Atlantic and Pacific Oceans since the early 1970s (Moore *et al.* 2001; Eriksen *et al.* 2013). Plastic debris and microplastics are transported by ocean currents across borders and are found even in very remote areas such as the deep ocean (UNEP 2016b). While some microplastics float, others sink. Plastic bags and containers that decompose make up a large share of floating plastic wastes. Lighter weight polyethylene, polypropylene and polystyrene are the most common types of plastic litter in surface waters. This debris tends to degrade under the stress of sunlight, heat and agitation into tiny fragments that may be swept into gigantic gyres on the surface of several oceans. The amount of microplastics floating in the oceans has been estimated at 93,000-268,000 tonnes (Eriksen *et al.* 2014; Sebille *et al.* 2015). Denser polymers such as polyester and polyvinyl chloride tend to sink into the sediment of the marine environment and accumulate on the ocean floor, which means that a significant amount of microplastics may eventually accumulate in the deep sea and ultimately in marine and human food resources (Seltenrich 2015). It has been estimated that some 94 per cent of the plastic that enters the oceans ends up on the sea floor and about 1 per cent is found at or near the ocean surface (Lebreton *et al.* 2017).

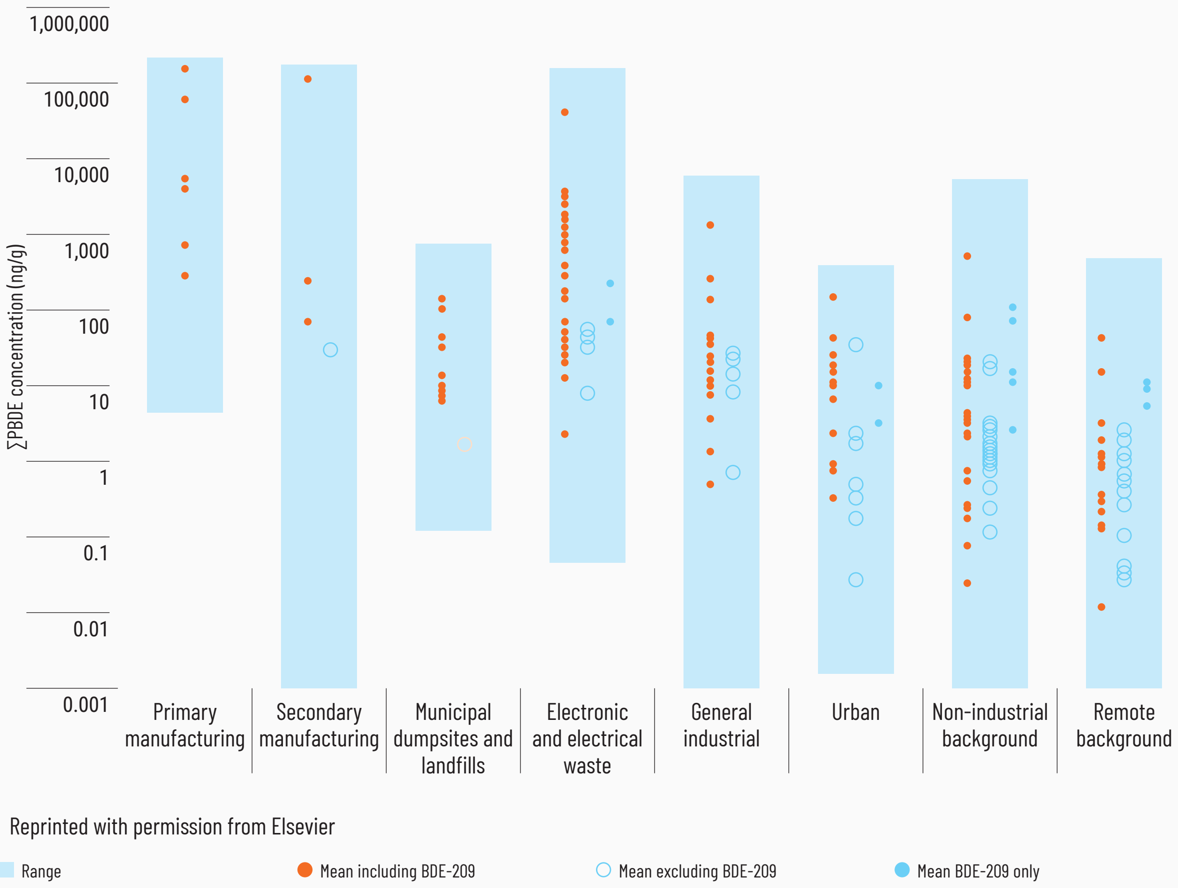
## 6.2.3 Soils

### Soils throughout the world are contaminated by a broad range of hazardous chemicals

Based on the analysis of soil samples from six countries (the United States, China, Japan, Norway, Greece, and Mexico), a global median soil concentration for PFOA and PFOS was estimated to be 0.124 ng $g^{-1}$ and 0.472 ng $g^{-1}$ respectively (Strynar *et al.* 2012). Higher concentrations of PFOA and PFOS for soils from Shanghai, China and Kampala, Uganda have been reported (Li *et al.* 2010; Dalahmeh *et al.* 2018). Perfluorinated compounds have been found in all soil and water samples in a recent national survey in the Republic of Korea of agricultural soils near wastewater treatment plants. Significant mean concentrations of PFOA and PFOS were found in samples from all 81 cities where these were drawn (Choi *et al.* 2017).

Soil acidification is now a major problem in China, where soil has long used for intensive agriculture. Large amounts of metals (e.g. cadmium, arsenic and chromium) have found their way to farmland through air deposition, synthetic fertilizers and livestock manure application (Chen *et al.* 2018). A 2017 study reviewing 465 published papers found that almost 14 per cent of grain production in China was affected by heavy metal pollution in agricultural soil (Zhang *et al.* 2015). In the Republic of Korea, monitoring data reveal an unexpected increase in average soil concentrations of dioxins and furans over a 10- year period (1999-2009). Soils from the country's industrialized regions showed a 10- fold increase in the same period (Kim and Yoon 2014). In a recent study in Mali, hazardous pesticides, including DDT, endosulfan

**Figure 6.8** Concentrations of polybrominated diphenyl ethers (PBDEs) in surface soil by land use category (ng/g) (adapted from McGrath *et al.* 2017)




Reprinted with permission from Elsevier

and profenofos, were detected in 77 per cent of soil samples collected from damaged cotton production sites (Dem *et al.* 2007).

Polybrominated diphenyl ethers (PBDEs) are commonly detected at background locations in surface soils, including in Antarctica and the northern polar regions. As shown in Figure 6.8, PBDEs emitted from numerous land use categories are routinely detected in surface soils.

### POPs are present in soils near recycling sites

In India, PCBs and PCDD/PCDFs have been found in soils near informal e-waste recycling sites and nearby open dumpsites of large cities (Chakraborty *et al.* 2018). This is attributed to the burning of wire during the copper extraction process, as well as combustion of plastic materials. In China, Leung *et al.* (2007) found that surface soils at a site where computer parts (e-waste) had been dismantled and recycled for a decade had high concentrations of PBDE and PCDD/PCDFs, with open burning among the major causes.

### Heavy metals are present in soils across regions

Various studies have identified heavy metals in soils. For example, a study of the impacts of industrial and agricultural activities on soil concentrations of copper, cadmium, mercury and lead in Zhangjiagang City, in a rapidly developing region of China, revealed high metal concentrations in local areas near industrial locations (Shao *et al.* 2014). Another study of soils along major roadsides in the Kwara State of Nigeria found high concentrations of heavy metals including lead, copper and zinc (Ogundele *et al.* 2015). An Australian study tracked reductions in lead soil samples following the government-


required phase-out of lead additives in fuels. There had been a significant decline over a decade, although legacy concentrations were found to be subject to remobilization (Kristensen *et al.* 2017).

### Plastic particles are widely found in soils

Plastic particles are widely found in soils (Bläsing and Amelung 2018; Scheurer and Bigalke 2018; Weithmann *et al.* 2018). The density of microplastics in soil has been found to be significantly higher than in marine environments (up to 23 times, depending on the environment) (de Souza Machado *et al.* 2018). Recently in China, plastic particles were found in all sampled soils, of which 95 per cent were in the microplastic size range (Zhang and Liu 2018). According to Boucher and Friot (2017), “about 52 per cent of the microplastic loss is trapped in soils when wastewater treatment sludge is used as fertilizer and/or when particulates are washed from the road pavement”.

## 6.3 Concentrations in biota

Concentrations of many manufactured chemicals build up in wildlife and increase as they move up food chains, where bioaccumulation results in the highest concentrations occurring in animals at the highest levels of the food web.

### Concentrations of POPs in some fish are declining, but unevenly

Data from Canadian Arctic monitoring reveal that concentrations of poly- and perfluoalkyl substances (PFASs) in landlocked freshwater fish are declining. However, some benthic species such as burbot (*Lota lota*) show increasing trends in some regions (AMAP 2017). Although concentrations of the sum of PCBS congeners (∑PCBs) in Great Lakes fish show continued declines (3-7 per cent per year since the 1970s), concentrations of penta- and hexa-bromodiphenyl ethers appear to have plateaued in fish from the Great Lakes, beginning in the early 2000s, and concentrations are declining (Environment Canada and US EPA 2014; Gandhi *et al.* 2017). The sum of these PBDEs measured between 2008 and 2012 was highest in Lake Ontario, followed by Lake Superior; the lowest concentrations were observed in fish from Lake Erie (McGoldrick and Murphy 2016). The most abundant organochlorine pesticides measured were DDT and its metabolites (DDE and DDD), the highest average concentration of which was measured in fish from Lake Ontario.

## Halogenated chemicals are found in birds worldwide

Global reviews of PBDE contaminations in birds have revealed that concentrations of PBDE are generally higher in terrestrial birds than in freshwater or marine birds, and that concentrations in terrestrial birds – particularly of the chemical mixture deca-bromodiphenyl ether(deca-BDE) – were highest in North America and China (Chen and Hale 2010; Law *et al.* 2014). In one study (Chen and Hale 2010) terrestrial birds had higher deca-BDE concentrations than aquatic birds. In another study examining perfluorinated compound concentrations in five different bird species from the same geographic region in Belgium, the highest mean liver perfluorooctane sulfonate (PFOS) concentrations were found in the grey heron with the lowest concentrations in the Eurasian collared dove (Meyer *et al.* 2009).

## Mercury is a common contaminant in wildlife

In recent surveys, marine fish species have generally had substantially lower mercury concentrations than freshwater fish. Increasing trends in mercury concentrations have been found in species in North America (Figure 6.9) and west Greenland, while decreasing trends in methylmercury concentrations have been found in east Greenland and the European Arctic (UNEP and AMAP 2018) (Figure 6.10). Egg mercury concentrations for marine birds from the Canadian Arctic indicate that mean mercury concentrations in ivory gulls are above threshold levels for adverse effects on reproduction.

Mercury concentrations are decreasing in polar bears in several regions, including Svalbard, Norway and the southern Beaufort Sea. However, concentrations in the brain tissue of polar bears and beluga whales are generally lower than the levels associated with neurotoxicity in other mammals, although they remain high enough to cause neurochemical changes that can precede overt neurotoxicity (Scheuhammer *et al.* 2015). Harbour seals from the western Hudson Bay had elevated mean liver mercury concentrations, along with comparatively high muscle mercury concentrations (Scheuhammer *et al.* 2015).

Long-term monitoring of mercury concentrations in Sweden, Finland, Norway and the Kola Peninsula of Russia show a consistent and significant decreasing trend in a number of lake fish species, paralleling a similar decline in atmospheric concentrations in the region (Braaten *et al.* 2017). In North America studies often report inconsistent, diverging or mixed trends in concentrations, particularly among aquatic biotic factors. Early declines are attributed to decreases in atmospheric mercury concentrations and deposition rates. Explanations for subsequent reversals or plateaus in concentrations include increasing local emissions, food web changes and climate change (UNEP and AMAP 2018). Overall, however, the updated *Global Mercury Assessment* concludes that "mercury loads in aquatic food webs are at levels of concern for ecological and human health around the world" (UNEP and AMAP 2018).

**Figure 6.9** Mercury concentrations in large lake trout collected from the East Arm of Great Slave Lake, Canada (µg/g), 1992-2012 (adapted from Evans *et al.* 2013, p. 12794)

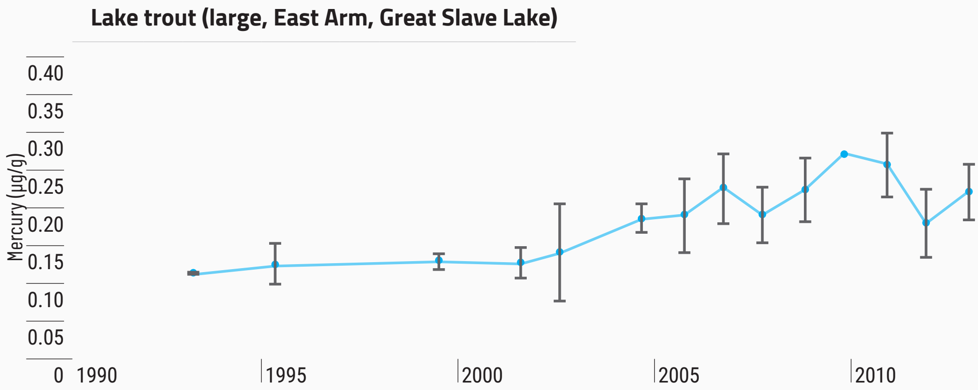
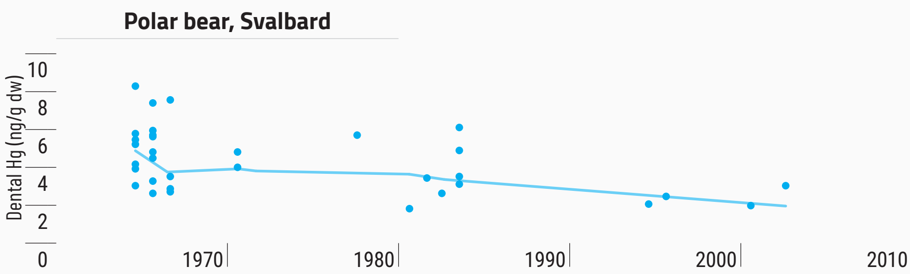



**Figure 6.10** Mercury concentrations in polar bears, Svalbard, Norway (ng/g dw), 1960s-2000s (adapted from Aubail *et al.* 2013, p. 60)






Dry weigh (dw)

### Plastic particles accumulate in fish

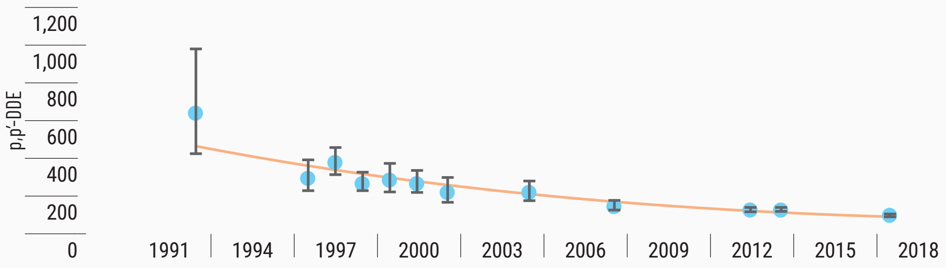
Microplastic particles are found in a wide variety of marine organisms, including species consumed as seafood (UNEP 2016b). One analysis of seafoods from different countries found plastic debris and fibres from textiles in most samples (Rochman *et al.* 2015). Another study found plastic pellets in the stomachs of 22 per cent of marine fish (Miranda and de Carvalho-Souza 2016). It has been estimated that fish in the North Pacific ingest 12,000 to 40,000 tonnes of plastic waste per year (Rios *et al.* 2007). A 2016 study (Rummel *et al.* 2016) found that 5.5 per cent of all investigated fish in the North and Baltic Seas had ingested plastic, the majority of which was microplastics.

## 6.4 Concentrations in humans

People throughout the world are exposed to low-dose mixtures of broadly heterogeneous manufactured chemicals. Evidence of concentrations of manufactured chemicals in humans is largely dependent on biomonitoring, which typically focuses on blood, breast milk, urine and hair. Biomonitoring studies show that some concentrations of manufactured chemicals in humans are decreasing, while others are increasing.

Continued, but mixed, progress is being made in reducing human blood lead concentrations. Monitoring studies across the world, including in the United States, Canada, South Africa and

**Figure 6.11** Blood concentrations (µg/kg plasma lipid) of p,p-DDE in pregnant Inuit women from Nunavik, Canada, 1992-2017 (adapted from AMAP 2015b, Appendix p. 65)




China, show declines. In Canada over the last two decades, a reduction in the level of lead in bone, an indicator of chronic exposure, has been observed (McNeill *et al.* 2017). Blood lead concentrations in children in some countries are declining, but less so in lower-income countries. Average blood lead concentrations (37.17 µg/litre), as measured in children aged 0-6 years from 11 cities throughout China in 2013, revealed continued high concentrations (Li *et al.* 2017b). A study of 2,861 children in the rural Philippines reported that 21 per cent had elevated blood lead concentrations (above 100 µg/litre) (Riddell *et al.* 2007). Hotspot lead exposure remains a concern for children globally. Mass lead intoxication events in Senegal (2008) and Nigeria (since 2010) illustrate the potential severity of such exposures in children (Clune *et al.* 2011).

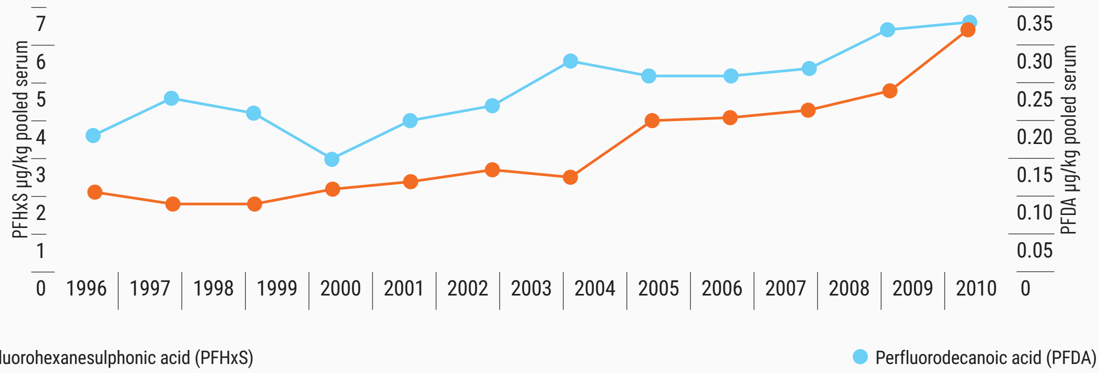
### Concentrations of some POPs in blood are falling in some countries, but not in others

The Arctic Monitoring and Assessment Programme's 2015 Assessment found that concentrations of most POPS regulated under the Stockholm Convention, including PCB and DDT in the blood of Arctic populations, had declined in past decades, while concentrations of some others such as HCB might still be increasing (AMAP 2015a). Figure 6.11 shows temporal trends for blood concentrations of dichlorodiphenyldichloroethylene (DDE), one of the compounds formed as a result of the breakdown of DDT in the environment. Concentrations of some POPs not regulated under the Stockholm Convention could also be increasing, for example perfluorodecanoic acid (PFDA) and perfluorohexane sulfonic acid (PFHxS) (Figure 6.12).

### There are significant variations in POPs concentrations in human milk across POPs, time, countries and regions

The second *Global Monitoring Report* on POPs (UN Environment and Secretariat of the Stockholm Convention 2017) found concentrations of PCDD/PCDF at relatively similar levels across both higher- and lower-income countries. The highest concentrations were found in the Africa and Western European and Others Group (WEOG) regions. Significant differences were observed among African countries, with Kenya and Uganda having the lowest observed concentrations of PCCDs and PCDFs in human milk while West and Central African countries including Côte d'Ivoire, the Democratic Republic of the Congo, Ghana, Mali, Nigeria, Sudan and Senegal had much higher concentrations. As regards indicator PCB in human milk, significant variations were found across regions, with much higher concentrations in the Central and Eastern Europe (CEE) and Western European and Other Groups (WEOG) regions compared to the Africa, Asia-Pacific and Group of Latin American and Caribbean Countries

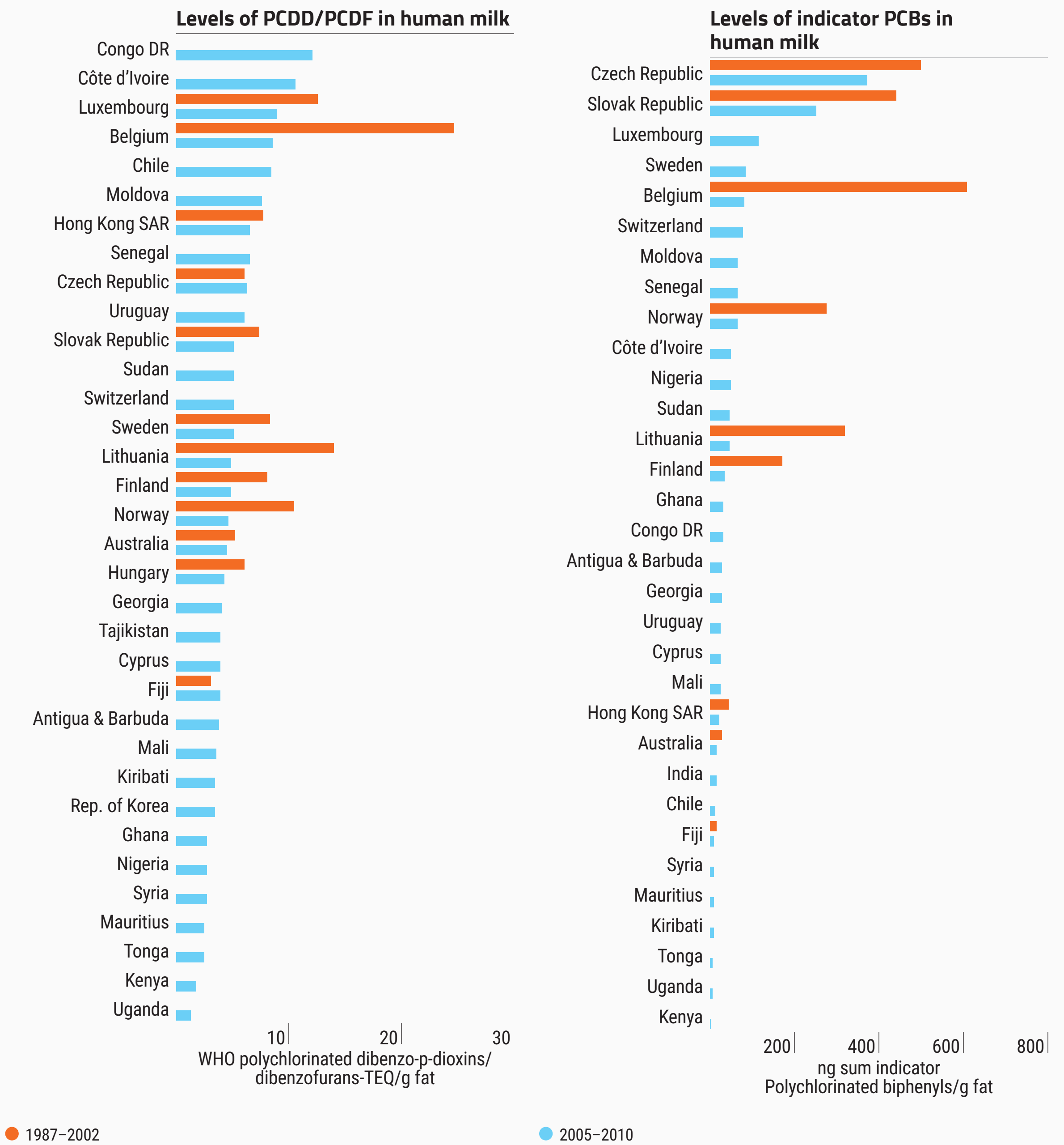
**Figure 6.12** **Concentrations of PFHxS and PFDA (µg/kg) in the blood of Swedish first-time mothers, 1996-2010 (adapted from AMAP 2015b, p. 49)**




(GRULAC) regions. The highest concentrations of ΣDDTs were found in less industrialized countries, including Côte d'Ivoire, Ethiopia, Hong Kong SAR, Uganda, Mali, Mauritius, Haiti, India, Solomon Islands, Sudan and Tajikistan. This distribution reflects DDT use in relation to the occurrence and prevention of malaria in these countries. Concentrations of PBDE in human milk also vary significantly across regions (UNEP and Secretariat of the Stockholm Convention 2017).

Data presented in the second *Global Monitoring Report* suggest positive trends over time for various POPs, although not consistently. Where concentrations of PCDDs and PCDFs in human milk have been measured at multiple time intervals over a decade (e.g. in Belgium, Ireland, New Zealand and Hong Kong), concentrations are steadily declining. Overall, data from the last decade suggest that PCDD/PCDF concentrations in human milk have fallen steadily from their earlier high levels, indicating the effectiveness of measures implemented to reduce environmental releases (Figure 6.13). In the case of PCBs the picture is less clear for some countries, although generally declining concentrations are observed (UNEP and Secretariat of the Stockholm Convention 2017).

**Figure 6.13** Levels of PCDD/PCDF (Sum 17 PCDD/PCDF) and indicator PCB (Sum 6 PCB) in human milk: survey results in 2005-2010 and comparison with 1980s levels (adapted and updated based on UN Environment and Secretariat of the Stockholm Convention 2017, p. 66)

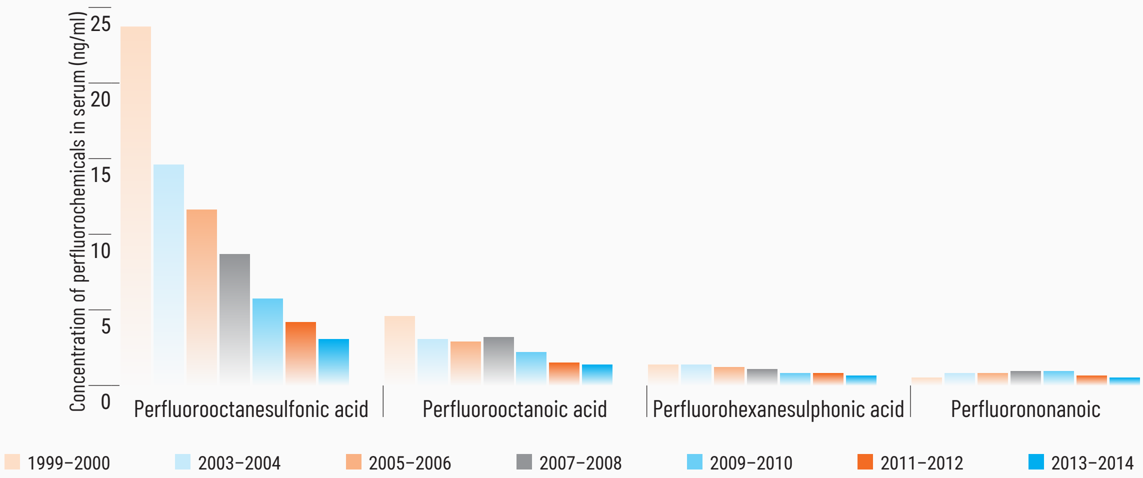



A recent review of the WHO/UNEP global surveys of PCDDs, PCDFs, PCBs and DDTs in human milk found that while the highest absolute concentrations were measured for DDT (more than 20,000 ng/g lipid), only a small share of the surveyed mothers had concentrations above the WHO safety levels. By contrast, virtually all mothers had concentrations of PCDD/PCDF as well as PCB above the WHO safety levels (van den Berg *et al.* 2017).

### Perfluorinated chemicals are ubiquitous, but concentrations appear to be declining in some countries

Both PFOS and PFNA are being detected in more than 98 per cent of serum samples from Alaskan Natives, and 92 per cent have shown concentrations of PFOA (Byrne *et al.* 2017). However, studies examining serum concentrations of the long-chain PFASs chemicals

**Figure 6.14** **Concentrations of perfluorinated compounds in the blood serum of women in the United States, 1999-2014 (median ng/ml) (adapted from US EPA 2017b)**




Note: To reflect exposures to women who are pregnant or may have become pregnant, the estimates are adjusted for the probability (by age and race/ethnicity) that a woman gives birth.

PFOA and PFOS over time have observed declines in countries where these chemicals have been phased out (US EPA 2013; Nøst *et al.* 2014; Stubleski *et al.* 2016; Eriksson *et al.* 2017; Schoeters *et al.* 2017). Studies of PFOA and PFHxS in human blood, archived by the German Environmental Specimen Bank, also documented mixed but gradual declines between 2001 and 2012 (Schröter-Kermani *et al.* 2013). Biomonitoring studies in Sweden and the United States of PFOA, PFOS and related long-chain compounds document similar declines in other cohorts, including pregnant women (Stubleski *et al.* 2016; Hurley *et al.* 2018) (Figure 6.14).

## Concentrations of flame retardants are highest in higher-income countries and are falling unevenly

Studies examining concentrations of flame retardant in mother's milk in the United States show high concentrations of polybrominated diphenyl ethers (PBDEs) (van den Berg *et al.* 2017). However, PBDE concentrations may be decreasing since they were phased out, as shown in analysis of concentrations in children between 1998 and 2013 (Cowell *et al.* 2018). Studies have detected previously banned flame retardants in the umbilical cord blood of newborn children in the United States, indicating one pathway, among others, for the transfer of legacy substances to new generations (EWG 2005; EWG 2009; Terry *et al.* 2017).

Studies examining organophosphorus flame retardants in some Asian countries show concentrations in the Philippines 1.5-2 times higher than those measured in Swedish populations (Kim *et al.* 2014). However, concentrations in Japan and Viet Nam are 4-20 times lower, suggesting that differences are likely attributable to differences in the use of flame-retarded products in each country (Kim *et al.* 2014). A recent study (Hoffman *et al.* 2017) that analyzed urine samples in the United States found that concentrations of the organophosphate flame retardant bis(1,3-dichloro-2-propyl) phosphate (BDCIPP) had increased strongly since 2002, with concentrations measured in 2014/2015 15 times higher than in 2002/2003.

National biomonitoring surveillance programmes in higher-income countries demonstrate recent declines in concentrations of brominated flame retardants. These declines are also being experienced in areas of China where these chemicals are produced (Li *et al.* 2017c). However, concentrations in some populations are notably elevated. For example, in California (United States) biomonitoring studies have revealed that PBDE concentrations among a cohort of firefighters (Park *et al.* 2015) were dramatically higher than national averages. Studies suggest that some PBDE concentrations in pregnant women in Canada may be lower than those in pregnant women in the United States (Fisher *et al.* 2016). Areas of China where flame retardant chemical manufacturing is occurring continue to have high concentrations of some PBDE congeners (Li *et al.* 2017c).

### Mercury concentrations in blood in some Arctic regions are declining, but are still among the world's highest

Although there has been a decline in the number of people living in the Arctic with mercury blood concentrations exceeding Canadian and United States guidelines, some (particularly those living in Indigenous communities, or those consuming large quantities of specific species of freshwater fish or marine mammals) have among the highest concentrations of blood mercury in the world. A significant proportion of women of child-bearing age from Indigenous communities living in the Eastern Canadian Arctic and Greenland still exceed these guidelines (AMAP 2011). However, declines are being observed: studies of pregnant Inuit and Nunavik women show decreasing concentrations, averaging a 4 per cent decrease per year since 1992 (AMAP 2015b) (Figure 6.15).

A review of national data available from nine countries found blood and urinary concentrations of mercury in most participants below 5 and 3 µg/litre, respectively, with concentrations significantly higher in adults than in children. Where data were available, overall decreasing trends in both blood and urinary concentrations could be observed. Birth cohort studies undertaken in a number of countries found the highest concentrations of methylmercury among populations consuming large amounts of fish and seafood or marine mammals (UNEP and AMAP 2018) (Figure 6.16). However, some of these countries have experienced strong decreases in methylmercury concentrations. Mercury concentrations also tend to be high (in some cases extremely high) among artisanal and small-scale gold miners (UNEP and AMAP 2018).

### Phthalate concentrations are decreasing in some countries, but increasing in others

Biomonitoring data from the United States in 2013-2014 demonstrate that urinary metabolites of diethylhexyl phthalate (DEHP) were detected in 62 per cent of women and 54 per cent of children, while dibutyl phthalate (DBP) metabolites were detected in 94 per cent of women and 98 per cent of children (US EPA 2013). Studies of trends in urinary metabolites of phthalates are seeing a rise in frequency and concentrations of the metabolite of Di-iso-nonylcyclohexane 1,2-dicarboxylate (DiNCH), often being used to replace DEHP and DiNP (Gyllenhammar *et al.* 2016).

**Figure 6.15** Concentrations of mercury and selenium in women's blood, Nunavik (Canada) (µg/L), 1992-2012 (adapted from AMAP 2015b, p. 31)

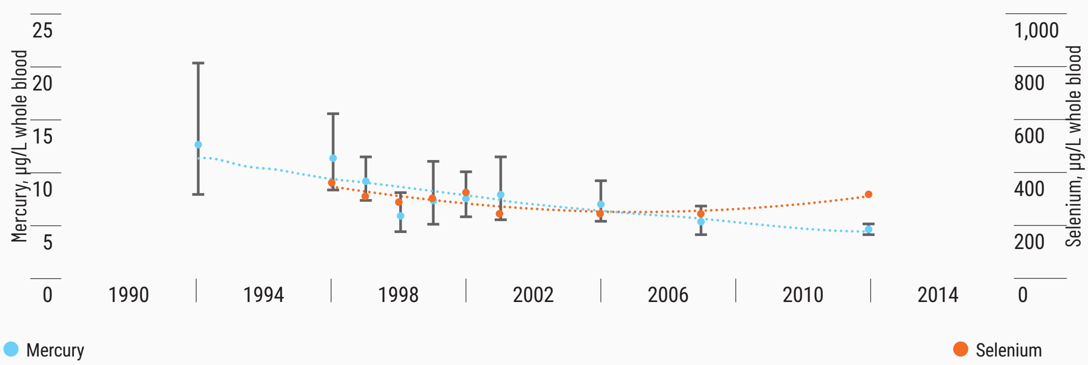
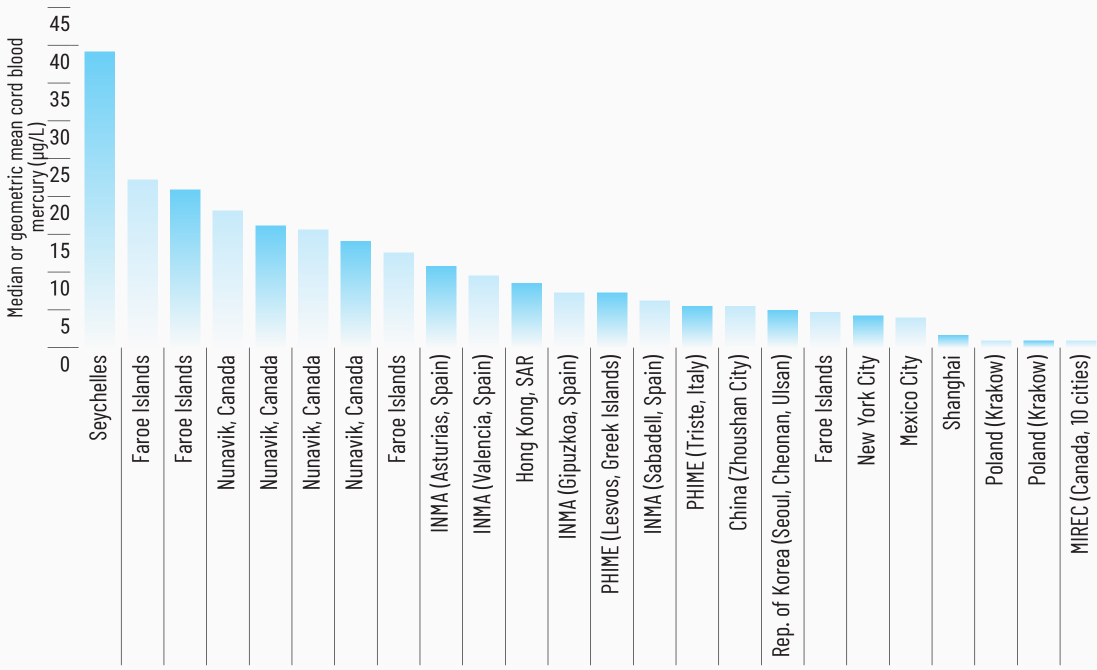


**Figure 6.16** Mercury concentrations in cord blood from birth cohort studies by country (µg/L), 2003-2016 (adapted from UNEP and AMAP 2018, p. 69)




### Concentrations of bisphenol A are decreasing, while concentrations of bisphenol S could be increasing

A recent literature review (Huang *et al.* 2018) found bisphenol A (BPA) concentrations in human urine in child and adult populations in Oceania, Asia, Europe and North America. However, it also found that restrictions on BPA use resulted in decreases in intake. In another study (Mendonca *et al.* 2014), BPA concentrations were found in 93 per cent of urine samples of infants without known exposure to it and in 75 per cent of their mothers' breast milk samples. Analyzing concentrations of four bisphenols in samples of adults in the United States taken over 14 years, a study (Ye *et al.* 2015) found BPA concentrations to be declining and concentrations of bisphenol S to be increasing, which could reflect trends in the use of the two substances. Measurable concentrations of bisphenol S in human urine are frequently reported (Wu *et al.* 2018).

## 6.5 Data availability, collection and analysis

### Global monitoring is improving, but substantive data gaps in environmental surveillance persist

Data on chemical concentrations vary significantly across regions, media and chemicals. Far more data are available from higher-income countries than from lower- and middle-income ones. There are more data from the northern than the southern hemisphere, and more human monitoring data from OECD than non-OECD countries. Nevertheless, substantial data gaps remain. Of the roughly 100,000 chemicals for which there is at least limited toxicity information in the US EPA's AcTOR database, there is exposure information for less than one-fifth. Readily accessible data on concentrations in exposure-related media are only available for a much smaller fraction (Egeghy 2012).

There is ongoing, though limited, global monitoring of various chemicals, including mercury, POPS and lead. There is far less monitoring of other chemicals. Efforts undertaken in the context of the Stockholm Convention's Global Monitoring Plan, as well as the Global Mercury Assessment, are important contributions to continuously improving global trends in concentrations of POPs and mercury, respectively. Most environmental monitoring provides data on concentrations at specific moments in time, while longitudinal data covering several points in time are much rarer. Insightful studies have been completed using monitoring data before and after a government regulation has been put in place, attempting to demonstrate an effect. More and better focused research of this kind is needed.

### Biomonitoring has made more information available on human exposures, although still more is needed

There has been an increase in human biomonitoring programmes. However, most surveys are limited to a small set of POPs and long-term trend data are primarily confined to monitoring studies conducted in developed countries. Global comparability of biomonitoring studies remains hampered by differences in data collection and reporting procedures. Both ongoing and newer programmes have expanded the list of chemical contaminants being measured beyond POPs to include other pesticides, bisphenol A, triclosan and phthalates, among others. However, most national programmes focus on surveillance of adults. There is a need for more studies on the elderly, adolescents, children and newborns, and/or perinatal experience among mothers (i.e. soon before or after giving birth). The United States National Health and Nutrition Examination Survey (NHANES), the Canadian Health Monitoring System (CHMS) and the Human Biomonitoring for Europe (HBM4EU) are important building blocks. The HBM4EU is a new joint effort of 28 countries to coordinate and advance human biomonitoring in Europe, and to provide better evidence of the actual exposure of citizens to chemicals and the possible health effects (HBM4EU 2018).

### Standardization of data collection and testing protocols would aid the pooling of data and identification of trends

While there are many studies of chemical concentrations in environmental media and human fluids, these studies are difficult to aggregate in order to identify trends. Comparability of studies is often limited because samples are taken differently, chemical identities are not fixed, study methods vary, and data are reported in varied units of analysis. There are very few global assessments. Review studies that try to assemble regional and global trend information, based on individual studies, are often limited by differing data measurement and analytical methods. Recent monitoring standardization efforts, such as the Stockholm Global Monitoring Programme and the Consortium to Perform Human Biomonitoring on a European Scale (COPHES), are making global assessments more possible and reliable. Greater efforts to coordinate and harmonize national and regional data to facilitate global assessments are needed.

# 7/ Environmental, health and social effects of chemicals

## Chapter Highlights

Chemical pollution is a major cause of human disease and premature deaths; the burden of disease from selected chemicals was estimated at 1.6 million lives and 44.8 million disability-adjusted life years (DALYs) in 2016.

Potential adverse health effects of chemical exposures include acute poisonings, cancers, reproductive and neurodevelopmental disorders, and disruption of the endocrine system.

Workers are often subject to disproportionally high exposures to hazardous chemicals. In 2015 it is estimated that almost 1 million workers died as a result of exposure to hazardous substances.

Foetuses, infants, children, pregnant women, the elderly and the poor are among the most vulnerable to the adverse effects of chemicals and waste.

Plastic litter has been linked to marine organism mortality and may also affect terrestrial animals.

Chemical pollution threatens ecosystem functions by adversely affecting pollinators, contributing to ocean dead zones, accelerating antimicrobial resistance, and increasing pressure on coral reefs.

The previous chapters in Part I addressed the increasing production and use of chemicals, releases to the environment, and concentrations. This chapter presents data and knowledge on the impacts of chemicals and waste on both human health and the environment. It is structured according to environmental effects, effects on biota and biodiversity, and human health effects. Attention is also given to social effects, including on vulnerable populations, men and women, and the poor. Prevailing data gaps, and challenges and opportunities in regard to acquiring pertinent knowledge, are briefly discussed.

## 7.1 Environmental effects

### Heavy metals and pesticides have left a legacy of contaminated soils

Soils worldwide have been damaged by mining, agriculture and industrial wastes that contain heavy metals, including lead, cadmium, chromium, mercury and copper. Heavy metals damage soil quality and reduce the number of the microorganisms that are critical to soil fertility. The sources of some of this damage dates back more than a century. For example, soils have been contaminated by lead arsenate (historically used as an insecticide in fruit orchards in Europe, North America and elsewhere), arsenic compounds (used extensively to control cattle ticks and pests on bananas in Latin America and other parts of the world) and DDT (Schooley *et al.* 2008).

There are ongoing activities across the world to inventory and remediate contaminated waste sites. The Toxic Sites Identification Program, a project of the Global Alliance on Health and Pollution (GAHP), has reviewed more than 3,000 hazardous waste sites and estimated that as many as 200 million people may be directly affected by such sites (GAHP 2013). The European Commission (EC) has estimated that there are over 3 million sites in Europe where past activities have polluted soils. Some 250,000 of these are in need of urgent remediation (Science Communication Unit, University of the West of England 2013). The United States Environmental Protection Agency lists 1,317 "Superfund" sites for clean-up. These sites present current or future threats to human health or the environment because hazardous wastes have been abandoned, accidentally spilled, or illegally dumped there (US EPA 2018).

Even as these efforts are under way, new contaminated sites are being created as a result of irresponsible waste management practices. Improper disposal of waste electrical and electronic products (including televisions, computers and mobile phones) pollutes surface and groundwaters and contaminates soils, particularly at dumping or landfill sites in low-income countries (Wäger *et al.* 2012). The accidental collapse of mining dams and landfills (e.g. in Spain in 1998, Romania in 2000 and Brazil in 2015) often leaves large areas contaminated with heavy metals (Grimalt, Ferrer and Macpherson 1999; UNEP and United Nations Office for the Coordination of Humanitarian Affairs 2000; Hatje *et al.* 2017). If pesticides are misused or overused, they can poison agricultural soil, reduce its resilience, and interfere with natural nutrient cycles. Stockpiles of banned pesticides kept in poorly maintained facilities across Sub-Saharan Africa, for example, have left a legacy of polluted soils (Blankespoor *et al.* 2009). Legacy soil pollution threatens local communities and food supplies, biodiversity and fragile ecosystems.

## Dead zones are expanding in marine and freshwater ecosystems worldwide

Many physical, chemical and biological factors combine to create "dead zones" (or hypoxia),

© UNEP/Usman Tariq, artisanal and small-scale gold mining site where oxygen levels cannot support life, in the open ocean, coastal waters and large lakes. Organic and nutrient enrichment related to sewage/industrial discharges and land run-off have led to increases in hypoxic zones in both marine and freshwater ecosystems in the last 50 years. Increasing nutrient loads can stimulate overgrowth of surface algae, which sink and decompose. The decomposition process depletes the supply of oxygen available to support organisms. While the largest marine dead zone appears to be in the northern Gulf of Mexico (United States Geological Survey 2018), dead zones also exist in the Baltic Sea, the Black Sea, and off the coast of Oregon, in Lake Eire and in Chesapeake Bay in North America (Díaz and Rosenberg 2011; Altieri *et al.* 2017; Breitburg *et al.* 2018; McCarty 2018).

### Significant damage to the atmospheric ozone layer has been halted

According to the 2018 Scientific Assessment of Ozone Depletion (World Meteorological Organization 2018), "as a result of the Montreal Protocol much more severe ozone depletion has been avoided. [...] Northern Hemisphere mid-latitude total column ozone is expected to return to 1980 abundances in the 2030s, and Southern Hemisphere mid-latitude ozone to return around mid-century. The Antarctic ozone hole is expected to gradually close, with springtime total column ozone returning to 1980 values in the 2060s. [...] The Kigali Amendment is projected to reduce future global average warming in 2100 due to hydrofluorocarbons (HFCs) from a baseline of 0.3-0.5°C to less than 0.1°C." As a result of ozone protection efforts, by 2030 up to 2 million cases of skin cancer may be prevented globally each year (van Dijk *et al.* 2013). It is estimated that at least 100 million cases of skin cancer and many million cases of cataracts will be avoided by the end of this century as a result of implementation of the Protocol (UNEP 2015). In the United States, among people born between 1890 and 2100, there could be, according to the US Environmental Protection Agency, 280 million cases of skin cancer avoided; approximately 1.6 million deaths from skin cancer prevented; and more than 45 million cases of cataract also prevented (US EPA 2015).

## 7.2 Effects on biota and biodiversity

### Hazardous chemicals adversely affect wildlife in various ways

In wildlife, high or prolonged exposure to certain chemicals leads to reproductive, immunological and neurological damage or even death. Many surfactants and heavy metals are toxic to aquatic organisms. Dioxins and PCBs adversely affect reproduction in turtles and some birds, correlating with smaller and more fragile eggs. PCB exposure has been implicated in the suppression of immune systems in seals and other marine mammals, contributing to mass die-offs in Europe in the late 1980s. Studies of sea turtles have found high levels of other perfluorinated compounds, which weaken the immune system and result in greater vulnerability to opportunistic infections (Swackhamer *et al.* 2009; Israel 2013). A 2018 study indicates that the drug diclofenac continues to adversely affect the health of the vulture population in India more than a decade after it was banned (Nambirajan *et al.* 2018).

Some endocrine-disrupting pharmaceuticals have been found to have adverse effects on wildlife (such as feminizing of male fish, preventing reproduction, or triggering population collapse) at very low concentrations (Kidd *et al.* 2007; Osachoff *et al.* 2014). A recent review of studies of chemical contaminants in marine ecosystems found that a wide range of chemicals had the general effect of reducing productivity and increasing respiration levels in wildlife (Johnston *et al.* 2015).

A Europe-wide study provides strong evidence that chemicals threaten the ecological integrity, and consequently the biodiversity, of almost half the continent's water bodies. This study, which tested for some 223 chemicals across 4,000 monitoring sites, found that organic chemicals were likely to have acute lethal effects on sensitive fish, invertebrates or algae species at 14 per cent of sites and chronic long-term effects at 42 per cent (Malaj *et al.* 2014). Some studies have also suggested that chemical pollution adds to existing pressures on the world's coral reef ecosystems (Box 7.1).

**Box 7.1** Coral reefs are under threat from chemical pollution

Oxybenzone, a chemical widely used in sunscreens, has been found to have damaging effects on coral planulae. According to a study undertaken in the United States, in Hawaii and in the US Virgin Islands (Downs *et al.* 2016), oxybenzone was shown to be a genotoxicant to corals and a skeletal endocrine disruptor. In Hawaii in 2018, the state legislature moved to prohibit lotions containing oxybenzone and octinoxate (State of Hawaii 2018). Danovaro *et al.* (2008) found that several chemicals in sunscreens – even at very low concentrations – cause rapid and complete coral bleaching, adversely affecting the biodiversity and functioning of reef ecosystems. Herbicides have also been reported to reduce the reproductive output of reef-building corals (Cantin, Negri and Willis 2007).



## By affecting insects and pollinators, pesticides may be jeopardizing ecosystem services

The continuous application of pesticides can deplete insect and microorganism populations, generating pesticide-resistant pests and adversely affecting predator-prey relationships. A recent study (Hallmann *et al.* 2017) found that the population of flying insects in protected areas in Germany had declined by more than 75 per cent during the previous 27 years. Loss of insect diversity and abundance could have cascading effects on food webs and jeopardize ecosystem services. A review by Chagnon *et al.* (2015) found that insecticides have significant adverse effects on ecosystem services such as decomposition, nutrient cycling, soil respiration and invertebrate populations. Adverse effects were noted among earthworms, which fulfil functions that are imporant for soil fertility, and pollinators.



Neonicotinoids, which are among the world's most widely used insecticides, can affect the sperm count of male honey bees and reduce the number of queen bees; they may also play a role in recent declines in bumblebee colonies. Adverse effects on pollinators, in turn, have direct effects on agricultural yields and food supplies (Moffat *et al.* 2015; Straub *et al.* 2016).

## Plastic litter has been linked to marine organism mortality and may also affect terrestrial animals

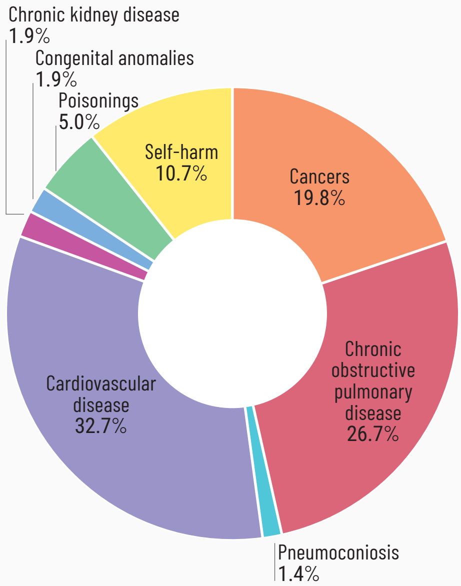
In the past decade, increasing public concern has arisen over the potential effects of marine litter on marine ecosystems. A report by UBA (Essel *et al.* 2015) notes that plastic litter in the oceans has adverse effects on 663 species, with more than half of them ingesting or becoming entangled in plastic debris. Fish and seabirds easily mistake microplastics floating at or below the ocean surface for food. Laboratory studies have confirmed that a variety of marine organisms, including zooplankton, have the capacity to ingest microplastics (Setälä, Fleming-Lehtinen and Lehtiniemi 2012; Cole *et al.* 2013). Moreover, plastic debris in seawater tends to adsorb POPs such as PCBs, DDT and PAHs which, if ingested, exhibit a wide range of adverse chronic effects in marine organism (Rios *et al.* 2010).

Microplastics also affect the health of terrestrial animals. Among other reasons, this may be due to the leaching out of hazardous chemicals (e.g. phthalates and bisphenol A) from plastic particles, which can harm vertebrates as well as invertebrates (de Souza *et al.* 2018). There is also evidence suggesting that microplastics adversely affect, for example, earthworms, which in turn may affect the soil condition (de Souza *et al.* 2018). Given a relative lack of scientific studies on this topic, calls have been made to further investigate the effects of microplastics on soil organisms (Norwegian Institute for Water Research 2018; Rillig and Bonkowski 2018).

### Releases of antimicrobials, heavy metals and disinfectants contribute to antimicrobial resistance

The WHO has identified the spread of antimicrobial resistance (AMR) as one of the 10 most important threats to global health in 2019 (WHO 2019). A review of the scientific literature concluded that the large majority of scientific publications found evidence of a link between antibiotic use in animals and AMR in humans (Review on AMR 2016). The environmental dimension of AMR was identified as an issue of emerging concern in a 2017 report by UNEP. Strong evidence indicates that releases of antimicrobial compounds to the environment, combined with direct contact between natural bacterial communities and discharged resistant bacteria, are driving bacterial evolution and the emergence of more resistant strains (Singer *et al.* 2016; UNEP 2017a). Moreover, evidence is emerging that biocides (such as triclosan) and heavy metals (including cadmium, copper, zinc and mercury) contribute to the spread of AMR because they increase the selection for antibiotic resistance genes among bacteria (Wales and Davies 2015; Singer *et al.* 2016; UNEP 2017a). The generation of microplastic wastes may be fuelling

**Figure 7.1** Deaths (total: 1.6 million) attributed to selected chemicals (per cent), 2016 (adapted from WHO 2018a, p. 2)




the spread of AMR, as plastic pollution facilitates increased gene exchange among bacteria (Arias-Andres *et al.* 2018; Imran, Das and Naik 2019).

## 7.3 Human health effects

### The burden of disease from chemicals is high

In 2018, the WHO estimated the disease burden preventable through sound management and reduction of chemicals in the environment at around 1.6 million lives and around 45 million disability-adjusted life years (DALYs) in 2016 (Figure 7.1). This corresponds to 2.7 per cent of total global deaths and 1.7 per cent of the total burden of disease worldwide for that year (WHO 2018a). These figures are likely to be underestimates, given that they are based only on exposures to chemicals for which reliable global data exist (including lead causing intellectual disability, occupational carcinogens such as asbestos and benzene, and pesticides involved in self-inflicted injuries). As shown in Figure 7.1, cardiovascular disease caused the largest share of deaths attributed to these chemicals, followed by chronic obstructive pulmonary disease and cancers.

The *Lancet* Commission on Pollution and Health (Landrigan *et al.* 2017) identified chemical pollution as a significant "and almost certainly underestimated" contributor to the global burden of disease, highlighting the gaps in data and knowledge on many chemicals in use. According to the Global Burden of Disease (GBD) Study (GBD Risk Factors Collaborators 2016), casualties from occupational exposure to carcinogens amount to 0.5 million, and those from soils contaminated by heavy metals and other chemicals to another 0.5 million.

### Lead is a priority pollutant for human health

According to data compiled by the Institute for Health Metrics and Evaluation (IHME) at the University of Washington (IHME 2019) in the Context of the Global Burden of Disease Study, in 2017 lead exposure accounted for more than 1 million deaths and the loss of around 24.4 million DALYs, with the highest burden in low- and middle-income countries. According to the WHO (2016), addressing lead exposure alone would prevent 9.8 per cent of intellectual disability, 4 per cent of ischaemic heart disease and 4.6 per cent of stroke.

## The preventable burden of disease from chemicals involved in unintentional acute poisonings was estimated at 78,000 deaths in 2016

For chemicals in acute poisonings, the disease burden preventable through sound management and reduction of chemicals in the environment was estimated at approximately 269,000 deaths and 15.4 million DALYs in 2016 (WHO 2018a). This includes the following sub-categories: pesticides involved in self-inflicted injuries were estimated to account for around 156,000 deaths and 7.4 million DALYs; chemicals involved in unintentional acute poisonings (methanol, diethylene glycol, kerosene, pesticides, etc.) were estimated at around 78,000 deaths and around 4.6 million DALYs; and chemicals involved in congenital anomalies were estimated to account for approximately 30,000 deaths and 3.2 million DALYs. These figures are based only on exposures to chemicals for which reliable global data exist. The World Health Statistics 2018 (WHO 2018b) found that "although the number of deaths from unintentional poisonings has steadily declined since 2000, mortality rates continue to be relatively high in low-income countries".

## Exposure to known chemical carcinogens increases the likelihood of cancer

Cancer is the second leading cause of death globally. It was responsible for 8.8 million deaths in 2015. The most common causes of cancer death are cancers of the lung (1.69 million deaths), liver (788,000 deaths) and colon (774,000 deaths). Approximately 70 per cent of deaths from cancer occur in low- and middle-income countries (WHO 2018c). In 2012, 57 per cent of new cancer cases, 65 per cent of cancer deaths and 48 per cent of five-year prevalent cancer cases were in developing countries (IARC 2012). The WHO has estimated that around 19 per cent of all cancers are attributable to environmental factors. This estimate includes indoor and outdoor ambient air pollution, second-hand smoke, asbestos, dioxins and other pollutants found in industrial emissions, constituents found

**Table 7.1** Total number of agents and POPs classified by the IARC Monographs per group (Volumes 1-123) (IARC 2018)

| Group | Description/ classification | Number of agents | POPs |
|---|---|---|---|
| Group 1 | Carcinogenic to humans | 120 | polychlorinated biphenyls; 2,3,7,8-tetrachlorodibenzo-p-dioxin; 2,3,4,7,8-pentachlorodibenzofuran; lindane; pentachlorophenol |
| Group 2A | Probably carcinogenic to humans | 81 | DDT; polybrominated biphenyls |
| Group 2B | Possibly carcinogenic to humans | 299 | chlordane; chlordecone; heptachlor; hexachlorobenzene; α- and β-hexachlorocyclohexanes; toxaphene (polychlorinated camphenes); mirex; polychlorinated paraffins (of average carbon chain length C12 and average degree of chlorination approximately 60 per cent) |
| Group 3 | Not classifiable as to its carcinogenicity to humans | 502 | Aldrin; dieldrin; endrin; hexachlorobutadiene; polychlorinated dibenzofurans (other than 2,3,5,7,8-PnCDF); polychlorinated dibenzodioxins (other than 2,3,7,8-TCDD) |
| Group 4 | Probably not carcinogenic to humans | 1 | none |

in food and drinking water such as pesticide residues, arsenic or aflatoxins, and ionizing and non-ionizing radiation (WHO 2011; Prüss-Ustün *et al.* 2016).

The International Agency for Research on Cancer (IARC), a specialized agency under the WHO, provides evidence on the carcinogenicity of agents (including chemicals, mixtures, occupational exposures) to humans or animals. Agents classified by the IARC Monographs are divided into four groups. Table 7.1 provides an overview of the more than 1,000 chemicals and other agents classified by the IARC to date, including classification of POPs regulated under the Stockholm Convention (not all have been evaluated to date, e.g. PFOS, HBCD). Five POPs are classified in Group 1. Of the proposed POPs (Secretariat of the Stockholm Convention 2017; Secretariat of the Stockholm Convention 2018), PFOA is classified as Group 2B and dicofol as Group 3.

A 2011 WHO report provided global statistics for two chemicals, asbestos and lead, which were classified as a carcinogen and a probable carcinogen, respectively. It estimated that asbestos exposures resulted in 107,000 deaths worldwide per year (Prüss-Ustün *et al.* 2011). Although social and genetic factors play critical roles in breast cancer causation, the role of some chemicals such as PCBs and ethylene oxide is well-recognized (Prüss-Ustün *et al.* 2016). Roughly 14 per cent of lung cancers are attributable to ambient air pollution and 17 per cent to household air pollution (Prüss-Ustün *et al.* 2016). Pesticide exposure of pregnant women has been found to increase the risk of childhood leukaemia in their children. Additional evidence supports a link between naturally occurring arsenic above a certain threshold in drinking water and the risk of bladder cancer (Turner, Wigle and Krewski 2010; IARC 2018).

## Laboratory studies show chemicals can cause disruption of endocrine systems and hormonal disorders

An increasing number of epidemiological studies show that environmental exposures to endocrine-disrupting chemicals (EDCs) (Box 7.2) are associated with human diseases and disabilities (Vandenberg *et al.* 2012; Di Renzo *et al.* 2015). Studies show that chemically induced hormonal effects can appear at exposures at extremely low dosages, although the science on this is not settled. Endocrine-disrupting chemicals include some pesticides, flame retardants, and components of fuels, plastics and plasticizers. A recent report by UNEP (2017b) lists several phenols, certain phthalates, bisphenol F and S, and four parabens, among others, as EDCs or potential EDCs. Recent studies address whether EDCs may be contributing to the increase in the

incidence of metabolic diseases such as type 2 diabetes and obesity (Heindel *et al.* 2015)

A 2012 review (Bergman *et al.* 2013) of the state of the science on endocrine-disrupting chemicals noted that many endocrine-related diseases and disorders are on the rise (e.g. low semen quality among many young men, genital malformations, adverse pregnancy outcomes, neurobehavioural disorders, cancers, obesity and type 2 diabetes). While genetic factors alone cannot account for the increased incidence of such diseases, a variety of factors can be involved, including (but not limited to) exposure to chemicals. While hundreds of chemicals are known or suspected EDCs, only a small share have been sufficiently investigated to identify overt endocrine effects in intact organisms. Significant uncertainties and knowledge gaps remain in the understanding of EDCs and their effects. However, this review noted that exposure of humans and wildlife to EDCs is widespread and that some associations

**Box 7.2 Endocrine-disrupting chemicals**

Endocrine-disrupting chemicals (EDCs) are chemicals that can alter functions of the endocrine system and consequently cause adverse health effects. The endocrine system consists of many interacting tissues that communicate with one another and the rest of the body by means of hormones. This system is responsible for controlling many processes in the body, from gamete formation to conception and early developmental processes such as organ formation, and most tissue and organ functions throughout adulthood. EDCs interfere in some way with hormone action and, in doing so, alter endocrine function and lead to adverse effects on the health of humans and wildlife. Some observed health effects associated with EDCs include, but are not limited to, cancer as well as reproductive, developmental, immunological and neurological disorders (UNEP 2017b).

with adverse effects have become apparent. Examples include high exposure to dioxins and PCBs as risk factors in breast cancer, and risks of prostate cancer related to occupational exposure to pesticides. The review also found that wildlife populations have been affected by EDCs, particularly due to some POPs, banning which has allowed some populations to recover.

### Exposure to some hazardous chemicals can harm reproductive capacities

Exposure to certain hazardous chemicals has been shown to effect sexual functioning and fertility in both women and men, as well as developmental disorders in the foetus and offspring. Preconception and prenatal exposure to toxic chemicals is a critical issue for both women and men of childbearing age. While adverse effects on reproductive outcomes can arise from a range of sources, some pharmaceuticals (e.g. thalidomide and diethylstilbestrol [DES], both now phrased out) are well-recognized hazards to reproduction.

Lead has long been known to be harmful to pregnancy. Maternal lead exposure, even at low levels, may be associated with reduced foetal growth, lower birth weight, pre-term birth and spontaneous abortion (US NTP 2012; Health Canada 2013). Other substances, such as alkyl phenols, alkyl phenol ethoxylates, polyethoxylates, bisphenols and various pesticides, have been associated in laboratory studies with a range of adverse reproductive health effects including sperm count decline, hypospadias and cryptorchidism in offspring, and cancer of the breast and testes (Rim 2017). A study of sperm count and sperm quality among a general sample of men in the United States found a significant association between adverse outcomes and the heightened urinary presence of several metabolites of phthalate esters, recognized as potential endocrine disruptors (Bloom *et al.* 2015).

Pesticides such as dibromochloropropane (DBCP) are associated with sterility (Thrupp 1991) and DDT exposures have been linked to pre-term birth (Longnecker *et al.* 2001), which has prompted regulatory action in many countries and at the global level. Phthalates such as dibutyl phthalate and DEHP are associated with reduced sperm count and motility (Wang *et al.* 2015). A recent cohort study conducted as a part of the Canadian Maternal-Infant Research on Environmental Chemicals found exposure to PFOA and PFHxS may reduce fecundability (Vélez, Arbuckle and Fraser 2015a). Exposure to triclosan has been associated with low fertility in epidemiologic studies (Vélez, Arbuckle and Fraser 2015b). Some research suggests that exposure to some nanomaterials may adversely affect reproductive systems (Vasyukova, Gusev and Tkachev 2015).

### Neurological health is affected by exposure to hazardous chemicals

The most common neurodegenerative ailments among the elderly include Alzheimer's, Huntington's and Parkinson's diseases and various neurodevelopmental disorders including learning disabilities, sensory deficits, developmental delays and cerebral palsy. While genetics and other factors play important roles in determining these outcomes, some common industrial chemicals (including lead, methylmercury, PCBs, arsenic and toluene) have been identified as potential causes of neurodevelopmental disorders and subclinical brain dysfunction. Exposure to these chemicals during early foetal development causes brain injury at doses much lower than those affecting adult brain functions (Grandjean and Landrigan 2006).

Lead exerts toxic effects in all parts of the nervous system. There is no known safe blood lead concentration. Even blood lead concentrations as low as 5 µg/decilitre, once thought to be a "safe level", may be associated with decreased intelligence, behavioural difficulties, and learning problems in children (WHO 2018d). Lead poisoning causes life-threatening encephalopathy (disruption of brain function), particularly in young children. There is a large literature on the neurodevelopmental toxicity of lead in children (Lidsky and Schneider 2003; Bellinger 2004; Needleman 2004; US NTP 2012; Lanphear

2015). The effects include reduced cognition and behaviour scores, changes in attention (including attention deficit hyperactivity disorder [ADHD]), impaired visual-motor and reasoning skills, and impaired social behaviour and reading ability. The brain is particularly vulnerable to lead exposure during early childhood. It interferes with synaptogenesis, the trimming of synaptic connections, and myelination during the early years of childhood growth (Lanphear 2015).

Neurobehavioural problems such as autism, ADHD and dyslexia affect about 10-15 per cent of children born in industrialized countries. The United States Centers for Disease Control and Prevention (US CDC) reported that one in 68 children in the United States had an autism spectrum disorder. Scientific evidence indicates that the incidence of both autism and ADHD in industrialized countries is increasing (US CDC 2014). While there is some evidence that chemical exposure is a contributing cause, the science is not conclusive. More conclusive is the effect of mercury and PCBs with respect to cognitive deficits. Research shows that there are critical windows of vulnerability during embryonic and foetal and infant development; during these periods exposures to chemicals such as some persistent organic pollutants (POPs), pesticides and lead are likely to cause learning disabilities, hyperactivity and other cognitive deficiencies (Rice and Barone 2000; Lanphear 2015). A 2016 study (Arbuckle *et al.* 2016) found concentrations of lead, and to a lesser extent bisphenol A and phthalates, in children's urine to be significantly associated with adverse behavioural indicators. Continued research has revealed an increasing number of chemicals with potentially adverse neurological effects (Grandjean and Landrigan 2014) (Table 7.2), including some phthalates (Arbuckle *et al.* 2016) and bisphenol A (Braun *et al.* 2017).

### Fragranced products and some chemicals contribute to multiple chemical sensitivity

Multiple chemical sensitivity (MCS) refers to a chronic disease in which low levels of chemicals invoke a multiplicity of unrelated symptoms. This disease has increasingly been recognized in several countries since the 2000s (Carman 2017). Chemicals associated with MCS include those found in cleaning products, pesticides, air fresheners and cosmetics. Steinemann (2016; 2018a; 2018b) reported strong evidence that some fragranced consumer products (as an important source of indoor air pollution) are also an important contributor to MCS and can cause adverse health effects such as respiratory problems, headaches and skin problems. A literature review found that sufficiently strong evidence in MCS diagnosis was currently lacking and called for further longitudinal epidemiological studies (Rossi and Pitidis 2018).

**Table 7.2 Chemicals identified by Grandjean and Ladrigan (2014, p. 333) as being toxic to the human nervous system, 2006 and 2013**

| Groups of chemicals | Number identified in 2006 | Number identified in 2013 | Number identified since 2006 |
|---|---|---|---|
| Metals and inorganic compounds | 25 | 2 | hydrogen phosphide |
| Organic solvents | 39 (including ethanol) | 40 | ethyl chloride |
| Pesticides | 92 | 101 | Acetamiprid, amitraz, avermectin, emamectin, fipronil (Termidor), glyphosate, hexaconazole, imidacloprid, tetramethylenedisolfotetramine |
| Other organic compounds | 46 | 47 | 1-3-butadiene |
| **Total** | **202** | **214** | **12 new substances** |

Some of the substances listed above continue to be the subject of scientific debate regarding their toxicity to the human nervous system.

## 7.4 Social effects

The benefits and risks of manufactured chemicals and chemical production are not equally shared across the world (Landrigan *et al.* 2017). Workers in developing economies are often exposed to heavy risks from hazardous workplace chemicals used in product manufacture, while consumers in high-consumption economies enjoy the benefits of inexpensive products. The suffering of the poor from polluted air and water often outweighs the benefits they gain from cheap products and foods. Women and children, particularly among the poor, are frequently exposed to disproportionate risks and lack the social or political means to protect themselves.

### 7.4.1 Vulnerable populations

Workers typically have higher exposures to hazardous chemicals than do other community members

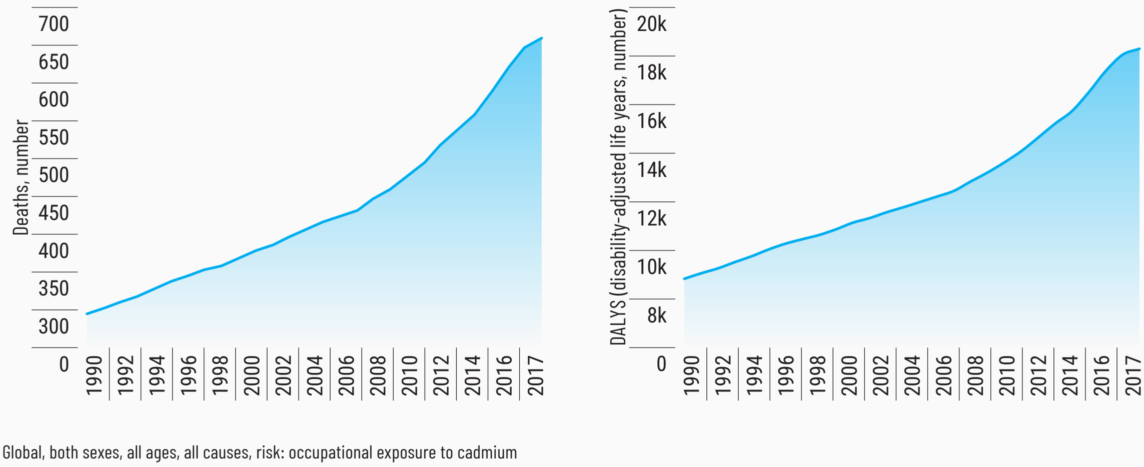
Specific conditions of work put workers at high levels of risk from chemical exposures, particularly those working in SMEs in developing countries and economies in transition, working in the informal economy, subject to shift work or working as migrant labourers. These workers are often subject to less regulated working conditions, have a higher risk of suffering health impairments, and have less access to health services (Santana and Rubeiro 2011; SAICM Secretariat 2016).

Where hazardous chemicals are used in industrial workplaces, the air can be contaminated with dusts and volatile chemicals released from materials, products and processes. Workers, who may spend eight or more hours there, may come into contact with significant amounts of these chemicals. There is no reliable way to determine the number of chemicals in workplaces around the world, or how many workers are exposed to these chemicals. Virtually every type of workplace in every sector uses chemicals, which means a wide range of workers are potentially exposed (ILO 2013a).

Workers are exposed to hazardous chemicals throughout the supply chain, from extraction, to manufacturing, to recycling and disposal. Of particular concern is the exposure of workers in chemical-intensive industries where the use of manufactured chemicals is rapidly expanding (including electronics, textiles, construction and agriculture), as well as services such as cleaning, maintenance, hairdressing, manicure and pedicure. Moreover, workers in lower-income countries are particularly at risk from exposure during informal recycling activities (Landrigan *et al.* 2017). For example, a study in Zimbabwe found significant adverse effects on workers from the management of hazardous

© UNITAR/Andrea Cararo, worker at a wastewater treatment plant in Ulaanbaatar, Mongolia

**Figure 7.2** Deaths and DALYs from occupational exposure to cadmium, 1990-2017 (adapted from IHME 2019)




waste (including paint, cleaning products and pesticides) in informal enterprises (Jerie 2016).

In 2015 almost 1 million workers died from exposure to hazardous substances, including dusts, vapours and fumes (an increase of more than 90,000 workers compared to 2011), based on estimates released by the ILO (Hämäläinen, Takala and Kiat 2017). Statistics from the Global Burden of Disease Database quantify the global effects of occupational exposure to cadmium in 2017 at more than 18,000 DALYs and around 659 deaths in 2017 and show a steady increase in both metrics (IHME 2019) (Figure 7.2). Among other diseases, cadmium has been associated with cardiovascular disease and cancer (Adams, Passarelli and Newcomb 2012; Tellez-Plaza *et al.* 2013).

## Endocrine-disrupting and carcinogenic chemicals put workers at risk

Worldwide, the highest exposures to carcinogens in terms of concentrations take place in workplaces. A 2016 WHO report estimated that 2-8 per cent of all cancers arose from occupational chemical exposures (WHO 2016). An extensive study of cancer in Great Britain found that 8,010 (5.3 per cent of all cancers) total cancer deaths in that country were attributable to occupation in 2004; out of the 339,156 cancer registrations in 2004, 13,598 were estimated to be attributable to occupational exposures while asbestos exposure accounted for 4,216 (Rushton *et al.* 2012). More specifically, the WHO estimated that 6 per cent of deaths from cancers of the lung, bronchus and trachea were attributable to chemicals found in the workplace. Occupational exposures to arsenic, asbestos, beryllium, cadmium, chromium, diesel exhaust, nickel and silica were estimated to cause 111,000 deaths (and 1,011,000 DALYs) from lung cancer in 2004 (Prüss-Ustün *et al.* 2011).

A series of studies from the United States and Asia published in the 1990s and 2000s reported increased risks of adverse reproductive outcomes among microelectronics workers, including spontaneous abortions, menstrual aberrations, infertility, birth defects and cancer in offspring. Despite increased corporate and government attention to the hazards of lead, nickel, arsenic and chlorinated solvents used in the industry, recent studies suggest that higher rates of spontaneous abortions and menstrual aberrations continue among electronics workers in the Republic of Korea (Kim, Kim and Lim 2015).

## Many chemical-related facility injuries and fatalities occur each year

While the chemical industry has implemented several programmes to prevent accidents at chemical manufacturing facilities, accidents at refineries, downstream manufacturing plants and other locations are reported to injure or kill hundreds of workers each year (Mihailidou, Antoniadis and Assael 2012; International Association of Oil and Gas Producers 2017; Zhao *et al.* 2018; OECD 2019). The best known example of a major chemical accident is the exposure of more than half a million people, including thousands fatally, to around 42,000 kg of methyl isocyanate and other gases released from a Union Carbide pesticide plant in Bhopal, India in 1984 (Broughton 2005). The EU tracks chemical accidents through its Major Accident Reporting (eMARS) System (EC 2018). A review of chemical accidents reported in the news media between October 2016 and September 2017 (Wood 2017) indicates that chemical accidents and near misses continue to occur frequently in OECD countries, but that fatality rates are lower than those in non-OECD countries. According to this study, OECD countries accounted for nearly two-thirds of events (421 out of 668), but barely one-third of deaths (201 out of 579).

### Occupational exposure to hazardous chemicals results in a wide range of chronic diseases

Diseases associated with exposures to hazardous substances are estimated to kill about 438,000 workers annually (ILO 2005). Common diseases associated with hazardous chemical exposures include asthma, asbestosis, byssinosis, silicosis, mesothelioma, bauxite fibrosis, contact dermatitis, berylliosis and chronic obstructive pulmonary disease. For example, working in building cleaning services that use commercial cleaners has been associated with new-onset asthma (Zock, Vizcaya and Le Moual 2010). Workers exposed to high levels of carcinogens are particularly vulnerable. Asbestos exposure alone claims over 100,000 lives every year, and this figure is rising (Prüss-Ustün *et al.* 2016).

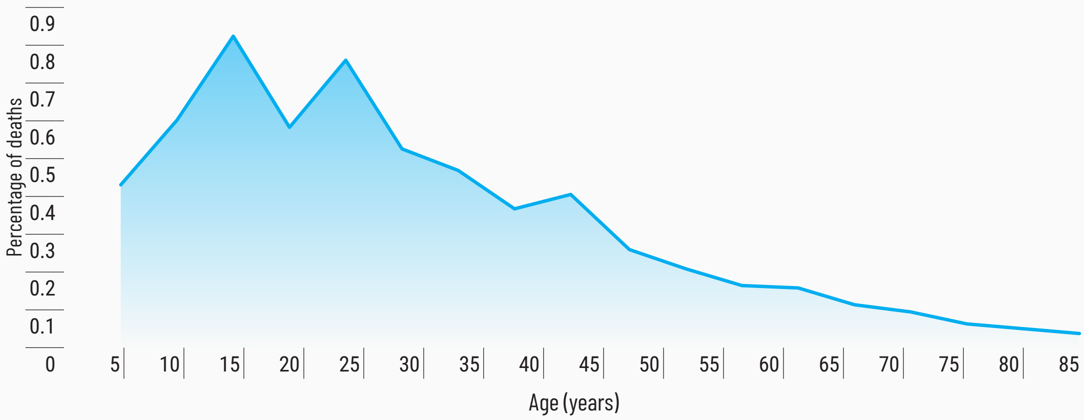
Agricultural workers may be exposed to high levels of pesticides while working in fields, or in local communities or camps where they live. Exposures in fields occur as a result of direct pesticide applications, pesticide drift from areal applications, and residues on plants or in soils. Protective clothing, training and regulatory enforcement are often lacking in both developed and developing countries.

Miners are also highly exposed to hazardous chemicals, particularly in developing countries. In many parts of the world minerals are extracted by artisanal and small-scale mining (ASGM). The large majority of the miners are very poor, exploiting marginal deposits in harsh and often dangerous conditions – and with considerable impact on the environment. Small-scale mining is thought to involve 13 million people directly and affect the livelihoods of a further 80-100 million (International Institute for Environment and Development 2002). Research in Ghana among ASGM communities found that more than 50 per cent of miners and 25 per cent of non-miners surveyed exhibited serious mercury toxicity and up to 7 per cent had neurological problems (Amankwah and Ofori-Sarpong 2014).

### Foetuses, infants and children are more susceptible to the risks of chemical exposure than adults

Children's health and development are compromised by exposures to a wide array of hazardous chemicals. Children are particularly sensitive to these exposures because of their higher body surface to weight ratio, differences in metabolism, ongoing organ growth and development, and lack of understanding and caution. Learning disorders, hyperactivity and attention deficits in children are associated with exposures of foetuses or infants to hazardous chemicals, including lead, mercury, manganese, dioxin and PCBs. During foetal development the brain is particularly vulnerable to some toxins, such as methylmercury and PCBs. Methylmercury affects the proliferation and migration of neurons; methylmercury and PCBs both affect synaptogenesis. Even small amounts of mercury in the diets of pregnant women have been associated with language, attention and memory impairment in their offspring (Bose-O'Reilly *et al.* 2010). The health of children and young adults is particularly affected by unintentional poisonings (Figure 7.3).

**Figure 7.3** Percentage of deaths attributed to unintentional poisonings by selected chemicals by age, 2016 (adapted from WHO 2018a, p. 2)




## Children in developing countries are at particularly high risk

Significant reductions in childhood blood lead levels have been documented in industrialized countries that have phased out leaded gasoline and lead in paints – although the WHO has estimated that 99 per cent of children with high blood lead levels live in developing countries where lead in gasoline and paint is still prevalent (WHO 2009). Children living in the vicinity of waste sites are particularly at risk. A study assessing 200 hazardous waste sites in 31 countries found close to 780,000 children to be at risk of diminished intelligence from exposure to lead (Chatham-Stephens *et al.* 2014).

The ILO has estimated the number of working children aged five to 14 to be 168 million worldwide, of which 60 per cent are engaged in agriculture. Some 85 million child labourers have been reported to be in hazardous work such as farming, construction, textiles, mining, tanning, ship breaking and fishing, including many who are exposed to toxic chemicals. Although in absolute terms middle-income countries are

host to the largest numbers of child labourers, the highest incidence of children working in hazardous occupations is in Sub-Saharan Africa (ILO 2011; ILO 2013b).

### The elderly are particularly susceptible to the risks of hazardous chemicals

Chemical exposures can aggravate compromised organs and increase vulnerability to opportunistic disease in the elderly. The ability of the body to respond to the physiological challenge presented by hazardous chemicals is dependent in part upon the health of the organ systems that eliminate those substances from the body (Risher *et al.* 2010). Older people are susceptible to the effects of mercury because of declining organ functions, and to air and water pollution because of impaired DNA repair mechanisms. Low-level exposure to lead may increase their risk of high blood pressure and the incidence of cognitive impairments and psychiatric symptoms (anxiety and depression) (Payton *et al.* 1998). Exposures to lead and PCBs have been linked to dementia, while Parkinson's disease has been linked to exposures to the manufactured heroin 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP), the pesticide rotenone and the metal manganese (Stein *et al.* 2008). Links between Parkinson's and Alzheimer's diseases and various solvents and pesticides are suspected, although the evidence is not conclusive (Allen and Levy 2013).

## 7.4.2 Gender

### Different factors determine chemical exposure for men and women

Social and cultural norms, family traditions and, in some countries, laws and regulations differentiate how men and women are exposed to hazardous chemicals. The differences include the kinds of chemicals encountered, as well as the concentrations and frequency of exposures. In addition, men and women differ in their physiological susceptibility to the effects of exposure to hazardous chemicals. Women are especially vulnerable to some chemicals during pregnancy and lactation, while the higher volume of fatty tissue in women's bodies makes them more vulnerable to fat soluble chemicals such as the halogenated hydrocarbons (UNDP 2011; SAICM Secretariat 2016; (WECF 2016). Men may be particularly at risk, for example, due to potential adverse effects on sperm quality (Rim 2017; Bloom *et al.* 2015).

### Gender differences in workplace exposure

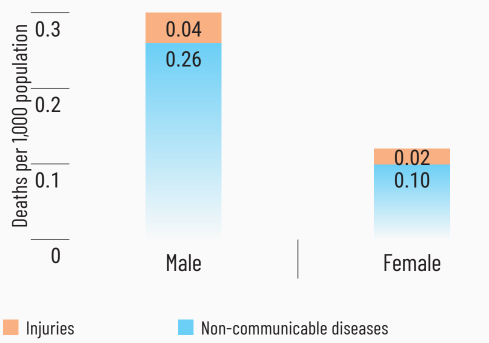
Often men are more likely than women to be engaged in physically dangerous occupations with high chemical exposures. In occupations such as fishing, mining, tanning, stone cutting, construction, boat disassembly and equipment handling, for example, men are more likely to be exposed to acids, solvents, heavy metals, asbestos, fuels and explosives; they are also more likely to be exposed at greater concentrations than women. Women make up most of the assembly line workers among supply chain vendors in emerging economies, particularly in electronics, toys and textiles, where they may be exposed to solvents, mastics, metals in paints and coatings, dyes, and textile finishing chemicals. In agricultural work women make up 43 per cent of the workforce (FAO 2011). While men are more likely to be directly exposed to pesticides during application, women and children are more likely to be indirectly exposed during planting, maintenance work and harvesting (Arbuckle and Ritter 2005; UNDP 2007; Pesticide Action Network Asia and the Pacific 2017). Pesticide exposure can affect women's fertility, reproductive health, menstruation patterns and risk of endometriosis (García 2003). In men occupational pesticide exposure can be associated with adverse effects on sperm quality (Martenies and Perry 2013; Miranda-Contreras *et al.* 2015; Cremonese *et al.* 2017).

### Gender differences in domestic exposure

Use of certain product types varies significantly by gender. This difference is often associated with conventional family roles and occupations. Where women work in homemaking, teaching, health care, elder care and child care, they are more likely to be exposed to soaps, detergents, food preservatives, cooking oils, solvents, insecticides, and pesticides used in vector control. Because women and girls usually assume responsibility for cleaning and household management, they are more likely than men to be exposed to toxic chemicals found in cleaning agents and sanitizers (UNDP 2011). According to the WHO (2018a), the disease burden preventable through sound management and reduction of chemicals in the environment is significantly higher for men (Figure 7.4), mainly due to their higher occupational exposure in certain sectors.

Women are significantly greater users of cosmetics and personal care products, many of which are directly applied on the skin (UNEP 2016; WECF 2016). They include skin lightening products, which often contain hazardous substances such as mercury. In some cultures women are likely to use large amounts of cosmetics, particularly perfumes, skin creams, nail varnishes, deodorants and hair treatments. One report has suggested that British women may put an average of 515 chemicals on their bodies every day (Rice 2009). Cosmetics and personal care products are among the most chemical-intensive products on the commercial market. Some 5,000 chemical ingredients are used in the personal care industry. Many products contain parabens, phthalates, propylene glycol, 1,4-dioxane, triclosan, diethanolamine, benzaldehyde and various other biocides, some of which are linked to allergies, asthma, endocrine disruption, reproductive damage and cancer (Ostojić 2016; SAICM Secretariat 2016). Women of colour have been shown to be particularly at risk (Zota and Shamasunder 2017).

**Figure 7.4** **Deaths attributed to selected chemicals, by gender, 2016 (adapted from WHO 2018a, p. 2)**




## 7.4.3 Poverty, social stratification and cultural aspects

### Chemical pollution disproportionally affects the poor

The poor in both higher- and lower-income economies are at a higher risk of disease and deaths caused by chemical pollution (GAHP 2013). Nearly 92 per cent of pollution-related deaths occur in low- and middle-income countries. Disease caused by pollution is most prevalent among minorities and marginalized populations (Landrigan *et al.* 2017). Such disadvantaged groups, which are disproportionally affected by the cumulative impacts of pollution and poverty, often lack the financial, social and political capacities to avoid such exposure, particularly in lower-income countries. In cities minority and disadvantaged people often reside in neighbourhoods near industrial areas, production facilities, waste dumpsites, waste treatment facilities, or polluted water or land; in rural areas the poor often reside near mining operations, agricultural fields sprayed with pesticides, livestock feeding lots, abandoned chemical stockpiles, waste disposal sites or polluted water sources (Goldman and Tran 2002; GAHP 2013; Collins, Munoz and JaJa 2016; Starbuck and White 2016).

A number of studies have found low-income individuals to have significantly higher exposures to diabetogenic EDCs (Ruiz *et al.* 2018). A study of the health effects of toxic waste sites in India, Indonesia and the Philippines concluded that the burden of disease from living near hazardous waste sites (measured in DALYs) is comparable to that from outdoor air pollution or malaria (Chatham-Stephens *et al.* 2013). In the United States living near industrial facilities has been associated with non-Hodgkin lymphoma (de Roos *et al.* 2010). Poor and disadvantaged people also often experience significant adverse chemical exposures at work. Where poor people find work either in industry, agriculture or the informal sector, they are more likely than higher-wage workers to work in dangerous, unregulated settings where exposures to hazardous chemicals are high (Rockefeller Foundation 2013).

### The housing of poorer people puts them at greater risk from hazardous chemicals

Low-income housing in industrialized countries may contain asbestos, lead and formaldehyde and be heavily sprayed with pesticides. Building materials in developing countries may be cheaply made or recycled, with little concern for possible chemical risks. Studies have shown that indoor air quality in low-income housing is often more hazardous than that in middle-income housing, as it has higher levels of contaminants such as lead, PAHs, allergens and pesticides (Rauh, Landrigan and Claudio 2008).

### Contamination through food can be higher as a result of poverty or traditional diets

In high-consumption countries where high-quality and organic foods are available to high wage earners, the food available to low-income people with limited means is high in preservatives and stabilizers and marketed in single-use plastic packaging that may contain phthalates, heavy metals and other additives (Rather *et al.* 2017). In developing countries the traditional meats, fish and vegetables available to the poor may be contaminated with pesticides and the residues of industrial pollution. Indigenous people reliant on traditional diets of fish and marine mammals may be among the most highly exposed to persistent, bioacumulative and toxic chemicals (PBTs) (Undeman *et al.* 2018). For example, studies in Canada showed that First Nations people consuming large amounts of fish (Marushka *et al.* 2017) and Inuit consuming marine mammals (Hu, Laird and Chan 2017) could have an elevated intake of PCBs, dichlorodiphenyldichloroethylene, and methyl mercury. In the United States a study of the Yupik people of St. Lawrence Island (Alaska) found PCBs in their blood at levels six to nine times higher than in that of the general population in the lower 48 contiguous states (Carpenter and Miller 2011).

## 7.5 Challenges and opportunities related to information about chemicals' effects

Examining trends in the environmental, health and social effects of manufactured chemicals worldwide is limited by the availability and quality of information; the capacity of science to characterize chemical mixtures and synergistic effects; and the research still needed to link chemical exposure with environmental, health and social outcomes.

### Effects information is still lacking for thousands of chemicals, although work is progressing

In the past 50 years corporations, governments and university research labs have documented the health and environmental effects of hundreds of manufactured chemicals. The OECD High Production Chemicals Programme and, in the EU, REACH registration dossiers have more systematically expanded this information, and some high production chemicals and substances such as lead, mercury, asbestos and PCBs are well-studied. However, a comprehensive inventory of the health and environmental effects of thousands of other chemicals is still lacking. There is a large volume of research on chemical effects that result in cancer and chronic obstructive pulmonary disease. However, chemical effects on reproductive, endocrine, immunological and neurological systems are less well-explored. There is substantial information on chemical effects on some plants and aquatic and terrestrial organisms that are conducive to laboratory study, but much less field-based research on chemical exposure effects.

There are many studies on occupational exposures, and much research on chemical effects on adult men. Only recently has more research appeared on the effects of chemical exposure on women and children. Little research has been conducted on such effects on the elderly, the poor, communities, or larger marine and terrestrial animals. The social effects of chemical exposures on communities, and the disparities of effects among subsets of the population, are little recognized or studied.

### Despite progress, significant challenges remain in understanding mixture effects and long-term, low-dose exposures

Important progress is being made in developing approaches and methods to assess mixture toxicity, and several reviews and guidance documents reflecting the state of science are available (OECD 2011; Meek *et al.* 2011; WHO 2017; US ATSDR 2018). Although the development of research methods for studying the multiple exposures and complex interactions of mixtures is advancing, methodological challenges remain in understanding cumulative exposure to various chemicals and related potential health and environmental effects and research in this area is continuing to help ensure a high level of protection (Kortenkamp, Backhaus and Faust 2009). Often humans and ecosystems are exposed to a heterogeneous set of compounds or products, some of which may have combinational or synergistic effects. Complex interactions can occur with mixtures of chemicals, such that the toxicological effects experienced as a result of such exposures may differ significantly from the laboratory-studies on the effects of the individual chemicals (EC 2011). For example, a study of the effects of five common pesticides mixed together, as opposed to individually, demonstrated an effect greater than a simple additive effect on the brain enzymes of steelhead salmon (Laetz *et al.* 2009). Understanding the effects of long-term and low-dose exposures to mixtures of chemicals, particularly among young children, is also limited. These topics are discussed in more detail in Part III.

### Causal relationships between exposures and effects are often difficult to establish

Diseases are multifactorial. They are often the result of both genetic and environmental factors. Establishing causal relationships is difficult due to various intrinsic factors that can hinder clinical and epidemiological studies, as well as a lack of consensus on appropriate study designs and research methodologies. Epidemiological studies often require long time periods, large populations, or both. Clinical studies provide results that may be difficult to extrapolate to existing conditions. Where controversies arise, multiple studies may generate contradictory results and lead to long delays in taking risk management decisions since the science has not been settled. In some instances, the best that can be achieved is plausible associations based on mathematical modelling; statistical associations; combinations of laboratory, experimental and field studies; or various forms of expert judgment (Adams 2003).

# 8/ The economic benefits of action and the costs of inaction

## Chapter Highlights

Various studies have estimated the economic benefits of action taken to reduce or avoid exposure to dangerous chemicals, and the costs of inaction under the current policy framework.

Robust economic analysis is challenging and is associated with uncertainties; refinement of methodologies is ongoing and further studies are needed.

There is evidence that chemical exposure places an economic burden on health care systems, and that it reduces the productivity and capability of the workforce and the well-being (or utility) of wider populations through reduced disposable incomes and increased suffering.

The costs associated with exposure to harmful chemicals are estimated to be in the range of several per centage points of global GDP; likewise, the economic benefits of action from preventing chemical exposure are significant.

A study of the economic and social effects of using harmful chemicals could help to raise awareness of the global scale of chemicals and catalyse further action.

Large numbers of chemicals are manufactured, distributed, and incorporated into mixtures, articles and products globally. They provide a wide range of essential functions, generating substantial economic value and social benefits. These benefits arise at the point of sale (and along various supply chains) from the functionality that chemicals impart in products, the efficiency they support in manufacturing, and the process and product innovations they enable. Throughout a product's life cycle, however, exposure to harmful chemicals can cause damage to human health and well-being, biodiversity, and terrestrial and aquatic wildlife. This chapter supplements the analysis provided in the previous chapters. It discusses economic aspects of the valuation of costs and benefits associated with chemicals, and examines the differences between private benefits (or costs) and social benefits (or costs); economists refer to social benefits/costs as "externalities". The available economic analysis – which is limited to a comparatively small number of substance-disease pairings and countries – is reviewed.

## 8.1 Externalities associated with chemicals across the value chain

In economic terminology, an externality may be referred to as a cost or benefit that affects a party which has not chosen to incur that cost or benefit. External costs may arise, for example, from the impaired functioning of ecosystem services, biodiversity loss, or harm to wildlife. Quantitatively relating the impact of chemical pollution (or of human consumption patterns) to ecosystems damage, biodiversity loss or harm to particular species remains challenging (Marques *et al.* 2017; Wilting *et al.* 2017; Chaplin-Kramer and Green n.d.). More economic analysis exists

of the external costs to human health that are attributable to chemical pollution.

Concerning chemicals and waste management, knowledge is emerging about the economic benefits of reduced exposure to harmful chemicals (the "benefits of action") along with analysis of the economic costs identified with exposure to these chemicals (the "costs of inaction"). Examples of the costs of inaction are the direct costs of health care and the indirect costs arising from time off work or impaired capability (Nordic Council of Ministers 2015). For business the costs of inaction could include provision of occupational health care, or litigation and reputational damage.

**Box 8.1 Externalities: the differences between market prices and social costs (Helbling 2017)**

Consumption, production and investment decisions often have effects on people who are not directly involved in these decisions: that is, they are external to specific transactions. These effects can be positive or negative. So-called "technical externalities" – where external effects impact the consumption and production opportunities of others, but the market price of the product in question does not reflect these external costs – are the most common.

Environmental pollution, from harmful chemicals or any other source, is a classic example of a negative externality. Polluters make decisions based on the marginal costs incurred by them and marginal benefits accruing to them through production. However, they seldom consider the external (or indirect) costs that society incurs as a result of the production of a good. The indirect costs are not borne by the polluter or passed on to the consumer. They are not taken into account in market prices or in economic transactions. The social costs of production are therefore greater than the private costs.

Negative externalities may be accompanied by positive externalities. Positive externalities could include investment in research and development (R&D), perhaps by the same polluter, resulting in functional benefits facilitated by chemical use in new products. These new products may support weight savings and longer product lifetimes – resulting in, for example, wider social benefits beyond the private cost.

The main problem with externalities is that market outcomes may not be efficient, leading to overproduction of goods with negative externalities and underproduction of those with positive ones. Externalities present significant policy problems when indirect costs (or benefits) are not internalized by individuals, households and companies in their economic transactions.

Environmental costs are distributed within and between countries. While significant methodological challenges, data gaps and uncertainties continue to exist, it is clear that the economic costs of exposure to harmful chemicals are not only globally significant but are currently underestimated (Landrigan *et al.* 2018). Since the publication of UNEPs report *Costs of Inaction on the Sound Management of Chemicals* (UNEP 2013), new economic analysis has emerged that has further raised awareness and sparked debate. Known risks are evolving and new ones are emerging. Much of the economic evidence available focuses on Europe and the United States, while disproportionate health and environmental burdens are being experienced in low- and middle-income countries (LMICs) (Attina and Trasande 2013; UNEP 2013; Trasande *et al.* 2016a; Landrigan *et al.* 2018).

### Scope of the review and analysis

The review and analysis in this chapter explore the current state of knowledge along two dimensions:

- *The economic benefits of action (BoA) or reduced or avoided damage to human health and/or the environment from reduced/avoided exposure to dangerous chemicals*. These economic benefits include estimated benefits arising from, for example, the number of lives saved or cases of cancer avoided. Estimates are typically ex-post (they "look back"), using information on effects from regulatory (or voluntary) actions already taken. However, they seek to guide, refine and improve future actions.
- *The economic costs of inaction (CoI) or damage to human health and/or the environment that are estimated to be occurring at present – or can reasonably be expected to occur in the future – under the current policy framework*. These costs point to the need for new or amended actions, either regulatory or voluntary or a combination of the two.

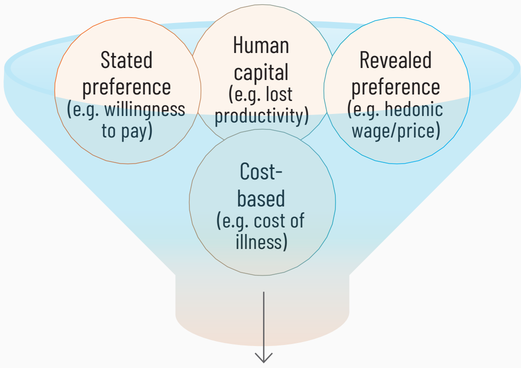
The entire literature is not covered in this chapter. Only published and/or peer-reviewed literature is referred to. No new estimates of economic value and effects have been generated for the purposes of this report. While any economic assessment of specific policy action should consider overall net effects, neither the wider economic effects related to innovation, nor the costs of regulatory implementation and compliance, are considered in detail. In addition, economic assessment is ongoing in public agencies in various jurisdictions around the world and in academia. In the case of the former it would not be possible to cover the large technical literature, although specific examples are noted. Much published academic work focuses on a relatively small number of substance-effect parings and is confined to studies in Europe and North America.

Any understanding of the economic burden of disease attributed to chemicals is limited by the scientific data. The strength or otherwise of evidence on causality between individual substances and health effects is an ongoing debate that continues to evolve as new associations are discovered (Harremoes *et al.* 2001). The focus of this chapter is on economic methods, and the results obtained in trying to chart these complex relationships, rather than on reviewing the epidemiological evidence.

## 8.2 How have economists identified costs and benefits?

Economic assessments of the BoA and CoI seek to reflect complex relationships. Robust economic analysis requires several earlier analytical stages, which are themselves subject to uncertainty and limited by the extent of epidemiological and biomonitoring data. Although significant effects on ecosystem services, biodiversity and wildlife have been identified, most *economic* analysis currently relates to the effects of chemical exposure on human health. Here the key methodological steps include: establishing

**Figure 8.1** **Identifying the economic costs of inaction and the benefits of action**




involves estimating the value of lost earnings from reduced/lost economic productivity due to disease, suffering or impaired capability. This is referred to as the *human capital* approach. Again, it relates to market-traded goods (i.e. labour and wages) but involves important assumptions about labour market participation, future earnings and discounting.

Directly or indirectly available market information may also *reveal individual preferences*. Examples are observing the wage differentials between risky and non-risky jobs, or differences in housing costs in different environments. Sometimes, to reduce the risk of death or suffering, individuals or firms incur voluntary expenditures ("avertive" expenditures) such as those on safety equipment or occupational health testing and analysis. Again, this reflects the purchase and use of market-traded goods (i.e. equipment and expertise). The *stated preference* technique relies on asking people questions through carefully designed surveys to elicit their willingness to pay for certain interventions that would improve their health. Examples include the contingent valuation method (which involves asking questions on their willingness to pay) and conjoint analysis (which elicits preferences from particular combinations of attributes and alternatives). This technique does not involve the purchase of market-traded goods, but reflects *individual valuation*.

an epidemiological relationship (dose-response function) between chemical exposure and a specific health outcome; evaluating the role of chemical exposure in this outcome, alongside other factors; and considering the latency of the disease and incorporating data on exposure within and across populations. While the CoI may be determined using data on current exposure, BoA analysis requires longitudinal (before and after) exposure data to identify attributable effects of an intervention. Only then can judgements be made concerning the number of attributable cases and their monetary and economic effects.

Common approaches to identify the economic costs of inaction and the benefits of action are summarized below. One of these approaches is typically used when assessing the costs of inaction and benefits of action for any single chemical (Figure 8.1). One approach involves estimating the costs of ongoing exposure (or the avoided costs from avoided exposure). Both involve directly observing the costs of specific health treatments. This is referred to as the *cost of illness or avoided cost* approach. It is a *cost-based* approach reflecting market-traded goods (i.e. labour, wages and drugs/treatments). However, this approach excludes effects on those not in the labour force, especially the young and the old, and does not capture suffering experienced by the individual. Another approach

Commonly used output indicators for health are based on mortality (premature death), morbidity (disease) and health life years. These are expressed as disability adjusted life years (DALYs) and quality adjusted life years (QALYs), while further indicators such as value of a life year (VOLY) or years of life lost (YOLL) are used in identifying health-related costs (World Bank 1993; Prüss-Ustün *et al.* 2016; GBD 2016 DALYs and HALE Collaborators 2017). The value of statistical life (VSL) is estimated using either the revealed preference or the stated preference estimates. (OECD [2010] presents a meta-analysis of value of statistical life [VSL] estimates obtained in various countries, using stated preference methods.) However, methodological developments are far from static (Box 8.2).

**Box 8.2** **Current methodological developments: SACAME**

Coordinated by the OECD and funded by the European Commission, the Socio-economic Analysis of Chemicals by Allowing a better quantification and monetization of Morbidity and Environmental impacts (SACAME) project aims to support improved socio-economic analysis through better quantification and monetization of effects. In the longer term, the project's objective is to develop harmonized OECD methodologies for estimating the economic costs and benefits of managing chemicals, in support of implementation of the Strategic Approach to International Chemicals Management (SAICM) (OECD 2018).

To date, several project papers have been published exploring economic analysis in the context of several different chemicals/chemical groups, including phthalates (Holland 2018), formaldehyde (Hunt and Dale 2018a) and the solvent methyl-2-pyrrolidone (NMP) (Hunt and Dale 2018b). The papers also explore thematic methodological issues, such as the challenges of using benefit transfer methods (Navrud 2017), approaches for the assessment of perfluoroctanoic acid (PFOA) and persistent bioaccumulative and toxic (PBT) substances more generally (Gabbert 2018), and how chemical risk assessments can better support economic analysis in decision making (Chiu 2017). Several studies note variations in existing valuation studies, extensive data gaps, and the need for multidisciplinary expertise. Some also call for new primary evidence, particularly from Asia.

## 8.3 What the data tell us: interpreting the findings

Monetary valuation is an important aspect of this chapter, and of the field of policy analysis more generally. The section above noted whether methods are market-based or non-market-based approaches. In interpreting the studies that follow, while a comparison of the aggregate values identified with gross domestic product (GDP) is useful in dealing with market-based approaches, the same comparison may be insufficient and potentially misleading when economic analysis uses approaches that are not market-based (Box 8.3).

## 8.4 The benefits of action taken in the last 50 years are globally significant

### Global treaties have "locked in' major economic benefits, to accrue over this century

All countries are Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, which entered into force in 1989 (with several later amendments). Moreover, all countries are also Parties to the London (1990), Copenhagen (1992), Montreal (1997) and Beijing (1999) amendments. As at 30 October 2018, 58 Parties had ratified the Kigali amendment (2016) which will enter into force on 1 January 2019. As the loss of stratospheric ozone is avoided and the ozone layer recovers, several studies have sought to quantify the long-term effects of this multilateral environmental agreement (MEA). Much of the analysis concerns the United States, where the cumulative benefits of avoided cancers and cataracts have been estimated at up to US dollars 4 trillion (1990-2065). In Europe the associated benefits have been estimated at some euros 7 trillion (1990-2100), or around euros 300 billion per year (Amec Foster Wheeler *et al.* 2017; US EPA 2015).

The Minamata Convention on Mercury came into force much more recently, in August 2017, although national and international activities to monitor and reduce mercury exposure have existed for a number of years (UNEP 2016; US EPA 2018; UNEP n.d.). Implementation of this MEA, which addresses specific human activities that contribute to widespread mercury pollution, will help reduce global mercury pollution in the coming decades. Bellanger *et al.* (2013) estimated the monetary value of neurotoxicity prevention through methylmercury (MeHg) control in Europe: prenatal exposure was

### Box 8.3 Utility, economic value and economic cost

Utility is a measure of satisfaction/dissatisfaction that individuals obtain by consuming a certain good or service. For example, each individual draws satisfaction from the enjoyment of good health, leisure or another consumer good. Conversely, dissatisfaction arises from poor heath, excessive work or exposure to pollution. The additional satisfaction/dissatisfaction resulting from the consumption of additional units of each good is referred to as the marginal utility or marginal disutility.

Economic value is the amount of money each individual spends, or is willing to spend, to obtain the utility from a certain good. Again, if the good results in disutility, the individual may pay to avoid that good or accept some compensation to continue suffering from this disutility. This economic value is a measure of the maximum amount of money the individual is willing to pay/ able to pay to derive utility from the good.

Economic value and market price, however, need not be the same. The value of the good is the opportunity cost of obtaining that good, i.e. the amount the individual gives up to obtain it. The value of leisure, for example, is the potential wage income sacrificed to obtain it. Economic value can be provided by market price where markets are competitive and markets exist for the good.

Certain goods may not only have use values, but also non-use, existence or intrinsic values. In such cases the value and price cannot be the same. Human life, for example, has intrinsic value beyond any market price or effect; the lives of the older people and others not in the labour market are clearly not less valuable. In these cases, economists rely on various non-market valuation techniques to estimate the value of life. Therefore, costs refer to the economic costs or the opportunity costs of consuming a good (or bad). The cost of pollution is the opportunity cost of healthy life, or what the individual sacrifices to pay for his or her ill health.

associated with the loss of 600,000 IQ points per year, corresponding to a total economic benefit from removing methylmercury of around euros 9 billion per year, while the global benefits of neurotoxicity prevention were estimated at upwards of around US dollars 20 billion per year. The authors pointed out, however, that "the validity of such calculations is limited by the lack of exposure assessments" (Bellanger *et al.* 2013).

### The benefits of action based on chemical legislation are valued at least in "the high tens of billions' per year

Future policy actions can be informed by and benefit from evaluation of policy actions taken in the past. Since the 1960s, regulatory and voluntary actions combined have substantially reduced the aggregate costs associated with exposure to a range of harmful chemicals. It has been conservatively estimated that the benefits of these actions are in the "high tens of billions" of euros per year in the EU alone. These estimates were derived largely from effects on human health (including in the areas of cancer, neurodevelopmental effects and reproductive health), based on a series of case studies where sufficient data existed. As methods to aggregate monetary values improve and more data become available, the known value of such benefits of action is likely to increase, perhaps significantly (Amec Foster Wheeler *et al.* 2017). However, analyses have not yet captured the possible effects of new/increased and/or multiple exposures, or of so-called "regrettable substitutions". Similarly, the economic costs and benefits of a selection of restrictions under the EU's REACH Regulation have been evaluated (ECHA 2016; ECHA 2017).The economic costs of restrictions under REACH (data are not available for all cases reviewed) have amounted to euros 290 million per year. The monetary benefits, although these could only be identified in a relatively small number of cases, have been in the order of some euros 700 million per year.

In the United States a retrospective evaluation of the benefits and costs of emission controls, imposed by the Clean Air Act and associated regulations between 1970 and 1990, assessed the effects of sulphur dioxide, nitrogen oxides, particulate matter, volatile organic compounds, lead, ground level and stratospheric ozone, and ambient air quality (US EPA 1997). Only some of these emissions are included in typical assessments of "chemical" pollution. Health conditions and effects assessed in the evaluation included premature mortality, lost IQ points, hypertension and coronary heart diseases; hospital admissions; and respiratory related ailments, asthma attacks and restricted activity days. Total monetized benefits, realized between 1970 and 1990, were estimated at just over US dollars 20 trillion (central estimate). This compared to direct costs of approximately US dollars 0.5 trillion (US EPA 1997).

In January 2018 the Canadian Government published proposals for further controls to eliminate asbestos. Using break-even analysis, the impact assessment explored the number of avoided cases of lung cancer or mesothelioma required to meet the expected costs (Government of Canada 2018).

### Environmental improvements are clear, but it is more difficult to attribute monetary values

In Europe the environmental benefits of action on chemicals, both regulatory and voluntary, since the 1960s have also been assessed. Among the benefits identified are reductions in chemicals found in water used for domestic, agricultural and industrial purposes; evidence of recoveries in some fish populations and in their reproductive capacity; avoided damage to biodiversity and ecosystem services; increased protection of recreational activities/aesthetic value; and avoided damage to bird and insect life as well as contamination of land and soil, consistent with regulatory action (Amec Foster Wheeler *et al.* 2017). Attributing environmental benefits (e.g. for biodiversity conservation, or protection of ecosystem services and wildlife) to specific actions, or identifying and aggregating quantitative and monetary effects and the extent of data gaps, are challenging. Economic estimates are possible in fewer cases, and those available are more uncertain. As in the case of analyses of health effects, available studies are limited in terms of chemical substance and location. There is a risk that environmental effects will be overlooked in policy analysis and that early warnings will be missed.

## 8.5 Despite progress, the global costs of inaction are substantial

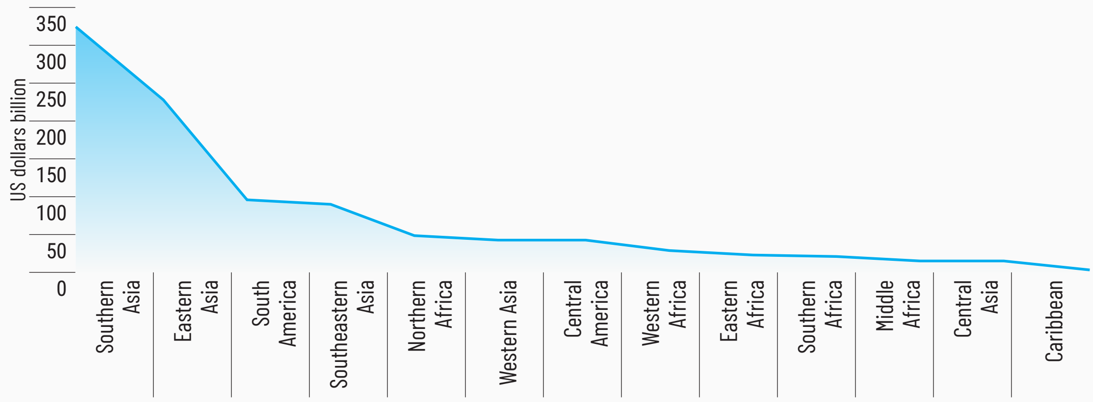
### The market and non-market costs of inaction could be as high as 10 per cent of global GDP

A global assessment of the disease health burden from environmental exposure to chemicals was published in Grandjean and Bellanger (2017). This study attempts to reflect a broader set of known chemical effect relationships (including subclinical effects) than those included in previous global burden of disease studies. The study indicates that calculations based on disability adjusted life year (DALY) are likely to understate effects, which may actually contribute costs exceeding 10 per cent of global GDP. Costs associated with neurotoxicants, air pollution and endocrine-disrupting chemicals (EDCs) were examined. It is important to note that the effects reported were based on both market effects (productivity effects or health costs) and non-market effects (willingness to pay valuation). This should be borne in mind when comparing results with respect to GDP. Future refinement of the estimates might usefully involve separating these effects.

### The costs of inaction are disproportionate in low- and middle-income countries

Although sparse, research has increasingly sought to establish the costs of inaction in LMICs (Landrigan *et al.* 2018). In the context of the Minamata Convention, Trasande *et al.* (2016a) evaluated the impact of mercury exposure as being between US dollars 77 million and 130 million at 15 sites in LMICs, using data on mercury levels in hair and effects on IQ, lost productivity and DALYs. This study built on earlier ones that looked at the economic effects of childhood lead exposure on lifetime productivity and earnings in LMICs more generally. These

**Figure 8.2** Lost lifetime earning potential for each cohort of children under five from childhood lead exposure in 2011 (US dollars billion) (adapted from Attina and Trasande 2013)




studies suggest the greatest burdens may now be borne in these countries, with total losses of up to around US dollars 1 trillion (some 1 per cent of global GDP), comprising US dollars 135 billion in Africa (4 per cent of GDP), US dollars 700 billion in Asia (some 2 per cent of GDP) and US dollars 140 billion in Latin America and the Caribbean (2 per cent of GDP) (Attina and Trasande 2013) (Figure 8.2).

## The public health costs from endocrine-disrupting chemicals are globally significant

Several recent studies have focused on costs from EDCs. They assess costs only from European exposure and from EDCs on which the authors consider that sufficient epidemiological studies exist. Several studies have used a weight of evidence characterization approach, adapted from that used by the Intergovernmental Panel

on Climate Change (IPCC). While the strength of evidence and probability of causation have differed and caused some debate, the effects assessed include IQ loss, autism, attention deficit hyperactivity disorder (ADHD), endometriosis, fibroids, childhood obesity, adult obesity, adult diabetes, cryptorchidism, male infertility, and mortality associated with reduced testosterone (Trasande *et al.* 2016b).

Although the key conclusions are not without uncertainties and data gaps, and have stimulated debate, they illustrate significant economic costs. They suggest that the costs of inaction are in the order of hundreds of billions of euros per year in Europe alone. Neurobehavioral deficits (IQ loss, ADHD and autism) represent around euros 150 billion per year (Bellanger *et al.* 2015), male reproductive disorders and diseases euros 15 billion per year (Hauser *et al.* 2015), female reproductive disorders euros 1.5 billion per year (Hunt *et al.* 2016) and obesity and diabetes in the order of euros 18 billion per year (Legler *et al.* 2015). Few studies have evaluated the cost burden of all the effects above. The suggested costs, after accounting for probability of causation, are in the hundreds of billions of euros: euros 157 billion (Trasande *et al.* 2015), which was later updated to euros 163 billion per year, over 1 per cent of the EU's GDP (Trasande *et al.* 2016b), or higher still (Rijk *et al.* 2016).

Additional studies have aimed to estimate costs for the United States and China. A 2016 study estimated the disease costs from EDCs in the United States at US dollars 340 billion (Attina *et al.* 2016). For China, a 2019 study (Cao *et al.*2019) estimated the total disease cost from exposure to EDCs at approximately Chinese Yuan 429 billion, equivalent to more than 1 per cent of national GDP. This overall estimate for EDCs was based on an estimate on the disease cost for male infertility, adult obesity and diabetes from exposure of the Chinese population to phthalates, which was estimated at more than Chinese Yuan 57 billion in health care costs in one year.

### Low-level exposure, even to well-studied and well-regulated chemicals, is an ongoing problem

Exposure to some chemicals has decreased substantially. Of these chemicals, the most extensively studied are heavy metals, particularly lead. However, exposure to lead in ceramics, batteries, paints, water pipes and waste continues to occur (Attina and Trasande 2013; Amec Foster Wheeler *et al.* 2017; Amec Foster Wheeler, Trinomics and Technopolis 2017). Low-level lead exposure in the United States has been associated with some 435,000 deaths per year from cardiovascular and ischemic heart disease. That figure is about 10 times higher than previously estimated, reflecting new evidence that associates cardiovascular disease with concentrations of lead once considered safe (Lanphear *et al.* 2018). Costs from IQ deficits and hospitalization associated with low birth weight babies, attributed to perfluorooctanoic acid (PFOA) levels in mothers, was estimated at some US dollars 350 million in 2013-2014, down from around US dollars 3 billion in 2003-2004 (Malits *et al.* 2018).

### Evidence on liabilities, compensation and reputational damage is limited, but the costs are significant

Limited evidence exists on the costs incurred by specific companies. A small number of high-profile incidents/accidents have involved fines of several million to several hundred million US dollars. Analysis of decision-making in these cases suggests that greater public disclosure of information might have reduced risks (Makino 2016; Shapira and Zingales 2017).

Historical liabilities can be responsible for ongoing financial costs. A good example is the compensation payable to individuals exposed to asbestos. In this case compensation pay-outs (as well as damage to human health) have continued long after extensive regulatory actions. This may reflect several factors, including: continued exposure to "historical" asbestos which is "locked" in older buildings; the long latency period between exposure and the onset of disease; and people living longer through treatment, hence requiring prolonged care. The Institute and Faculty of Actuaries has estimated total costs arising from all past, present and future asbestos claims in the United States at up to US dollars 275 billion, with costs of several billion US dollars each in France, Germany, Italy, the Netherlands and the United Kingdom (The Actuary 2002).

## 8.6 How effective are the methods used, and what are remaining challenges and data gaps?

### Challenges reflect multiple causal factors, the geographic scale and the latency of disease

Existing techniques have limitations. They cannot fully capture the costs incurred in terms of reduced quality of life, pain and suffering. Assessing the costs of illness requires accurate information on medical costs, but data are often missing on length of suffering, absence from work and hospital admission days, particularly in LMICs. Estimates are sensitive to the technology used and its efficiency and efficacy, which can vary between and within countries along with health care systems. Estimating the economic value of lost productivity requires making assumptions about labour force participation, future productivity growth and wages, and the marginal relationship between IQ and earnings. This approach also excludes effects on those not in the labour force, as well as wider effects on households. Better models are needed to establish linkages between cause and effect with greater certainty, and to incorporate effects from multiple exposures. This problem is compounded by extensive data gaps. (See Amec Foster Wheeler *et al.* [2017] on the extent and quality of existing data required for economic assessment.)

### Progress has been made, but challenges remain with respect to attribution and aggregation

Despite several new studies, quantifying physical impacts on human health so as to assign monetary values remains a challenge. The monetary values of impacts provide useful reference values for cost-benefit analysis, green accounting, and the assessment of the impact of regulations. However, there is a lack of data for quantifying (and assigning monetary values to) the physical impacts of chemical releases. This applies, in particular, to impacts on ecosystems and biodiversity, which is a major gap, recognizing initiatives such as TEEB (The Economics of Ecosystems and Biodiversity) to lay foundations and look at further methods (TEEB n.d.). Better information is required on the full spectrum of potentially problematic chemicals beyond a relatively small, well-studied group, many of which are already the subject of regulation. (See Sørensen *et al.* 2017 for a review of the valuation literature.) Further research is also needed in order to distinguish and attribute disease end points to specific chemicals, or groups thereof, from more general lifestyle or non-chemical environmental factors. As methods improve, however, the known benefits of action and costs of inaction are likely to increase, perhaps significantly.

## 8.7 Lessons learned and potential actions

Economic analysis helps to set out the underlying trade-offs inherent in the use of harmful chemicals. Much progress has been made: there is mounting, improving and more detailed analysis showing that ongoing chemical exposure places substantial economic burdens on health care systems, as well as undermining the productivity and capability of the workforce. These burdens are considerable at national and global levels, amounting to several per centage points of GDP.

"Pollution is very costly; it is responsible for productivity losses, health care costs and costs resulting from damages to ecosystems. But despite the great magnitude of these costs, they are largely invisible and often are not recognized as caused by pollution. The productivity losses of pollution-related diseases are buried in labour statistics. The health-related costs of pollution are hidden in hospital budgets. The result is that the full costs of pollution are not appreciated [and] are often not counted [...]".

*- Landrigan et al. 2018*

There is better analysis of economic damage, the spatial extent of such damage from local chemical use, the decision-making processes of business when addressing environmental externalities, and the distribution of burdens within populations and across countries (Landrigan *et al.* 2018).

Robust economic analysis is technically challenging. It requires several analytical inputs which are associated with uncertainties and debate (Bond and Dietrich 2017). These inputs include information on substance-disease pairings, specific dose-response relationship data, and information on exposure (across populations and over time) that are needed before judgements can be made about economic effects. While all economic analysis is subject to uncertainty and revision, significant data gaps and methodological challenges remain. Further analysis is required in order to verify effects and refine analytical methods. Drawing thematic conclusions from existing analysis becomes difficult due to differences in method, scoping and the time periods assessed, as well as differences in unit cost, valuation assumptions and approaches used. There is a need for more retrospective economic assessment, and for improved assessment of causal relationships, unintended consequences, and the effects of interactions among multiple chemicals and mixtures and among multiple regulations (Dudley 2017).

These considerations are offset by the relatively limited range of economic costs that it is currently possible to report. Overestimation may occur when extrapolating from uncertain cost data, and more work is needed on the verification of some effects. However, the economic costs of inaction (and the benefits of action) are likely to be understated for three reasons:

- While progress has been made, the economic analysis is drawn largely from a group of comparatively well-studied chemicals, several of which are regulated. A larger group consists of known or suspected pollutants whose effects are not quantified or to which a monetary value has not been attributed. A still larger group has not yet been studied.
- Even for the well-studied group of chemicals, current economic approaches do not currently permit the quantification of all known economic effects.
- Very little quantified/monetary analysis exists regarding effects on the environment (e.g. ecosystems, biodiversity, plant and animal life).

Substantial damage to human health and the environment has been reduced or avoided through extensive regulatory action. Global treaties have ensured that significant benefits are likely in the mid to long term. At a societal level, however, several health outcomes (e.g. incidence rates for several cancers) that are partly associated with chemical exposure (along with many other factors) appear to be worsening (Amec Foster Wheeler *et al.* 2017).

The available economic analysis is overly biased towards a small number of high-income countries. There is a disproportionate health burden in LMICs due to environmental exposure to chemicals, along with ongoing low-level exposure even to well-studied and well-regulated chemicals (Landrigan *et al.* 2018). Analysis also lacks national, subnational and social disaggregation. There is a pressing need for new research on a wider range of chemicals/groups, as well as on a wider range of end points and exposure routes. The need for new research and new exposure data, including concentrations of chemicals in humans (biomarker and biomonitoring data), is particularly urgent in LMICs. Consistent methods, consensus on unit values, and new empirical data on costs are required, building on the work of the European Chemicals Agency (ECHA n.d.), the OECD (2018) and other organizations and individuals.

The scale of the challenges posed by chemicals and waste are not matched by the attention paid to it by policymakers and the general public (Das and Horton 2018; Landrigan *et al.* 2018). A global study of the economic and social effects of using harmful chemicals, comparable to the Stern Review on the *Economics of Climate Change* (Stern 2007), does not exist. Such a study could raise awareness of the global scale of these effects and catalyse further action.

# References

## Chapter 1


American Chemistry Council (2013). *Shale Gas, Competitiveness, and New US Chemical Industry Investment: An Analysis Based on Announced Projects*. https://www.americanchemistry.com/First-Shale-Study/.

American Chemistry Council (2017). *2017 Year-End Chemical Industry Situation and Outlook*. https://store.americanchemistry.com/Business-of-Chemistry-Situation-and-Outlook.

Baltus, W. (2017). *Asian Markets for Bio-Based Chemical Building Blocks and Polymers*. Hürth: nova-Institut GmbH. http://bio-based.eu/media/edd/2017/01/17-01-SHORT-VERSION-Asian-bio-based-polymer-markets.pdf.

Bamber, P., Frederick, S. and Gereffi, G. (2016). *Philippines in Manufacturing Global Value Chains: Opportunities for Upgrading*. Durham, NC: Duke University. http://industry.gov.ph/wp-content/uploads/2017/08/The-Philippines-in-the-Chemical-Global-Value-Chain.pdf.

Bellon, T. (2018). U.S. judge affirms Monsanto weed-killer verdict, slashes damages, 23 October. *Reuters*. https://www.reuters.com/article/us-bayer-glyphosate-lawsuit/u-s-judge-affirms-monsanto-weed-killer-verdict-slashes-damages-idUSKCN1MX011. Accessed 30 January 2019.

Bomtempo, J.-V., Chaves Alves, F. and de Almeida Oroski, F. (2017). Developing new platform chemicals: what is required for a new bio-based molecule to become a platform chemical in the bioeconomy? *Faraday Discussions* 202(0), 213-225. https://doi.org/10.1039/C7FD00052A.

Boulamanti, A. and Moya, J.A. (2017). *Energy Efficiency and GHG Emissions: Prospective Scenarios for the Chemical and Petrochemical Industry*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2760/20486.

British Broadcasting Corporation (2017). S Korean exec jailed over toxic humidifier disinfectant, 6 January. https://www.bbc.com/news/business-38526697. Accessed 5 September 2018.

Budde, F., Ezekoye, O., Hundertmark, T., Prieto, M. and Simons, T.J. (2017). Chemicals 2025: will the industry be dancing to a very different tune? *McKinsey&Company*. https://www.mckinsey.com/industries/chemicals/our-insights/chemicals-2025-will-the-industry-be-dancing-to-a-very-different-tune. Accessed 3 September 2018.

Cayuela, R. And Hagan, A. (2019). *The Chemical Industry Under the 4th Industrial Revolution: The Sustainable, Digital and Citizens One*. Not yet published. Hoboken, NJ: Wiley-VCH Verlag GmbH.

Center for International Environmental Law (n.d.). *Fueling Plastics: How Fracked Gas, Cheap Oil, and Unburnable Coal are Driving the Plastics Boom*. https://www.ciel.org/wp-content/uploads/2017/09/Fueling-Plastics-How-Fracked-Gas-Cheap-Oil-and-Unburnable-Coal-are-Driving-the-Plastics-Boom.pdf.

Darkow, I.-L. and von der Gracht, H.A. (2013). Scenarios for the future of the european process industry - the case of the chemical industry. *European Journal of Futures Research* 1(1), 10. https://doi.org/10.1007/s40309-013-0010-9.

de Wit, M.,, Hoogzaad, J., Ramkumar, S., Friedl, H. and Douma, A. (2018). *The Circularity Gap Report: An Analysis of the Circular State of the Global Economy*. Amsterdam: Circle Economy. https://docs.wixstatic.com/ugd/ad6e59_733a71635ad946bc9902dbdc52217018.pdf.

de Wit, M., Verstraeten-Jochemsen, J., Hoogzaad, J. and Kubbinga, B. (2019). *The Circularity Gap Report 2019*. Amsterdam: Circle Economy. https://www.circularnorway.no/wp-content/uploads/2019/01/ad6e59_ce56b655bcdc4f67ad7b5ceb5d59f45c.pdf.

Deloitte (2016). *On the Board's Agenda – M&A: The Intersection of Due Diligence and Governance*. https://www2.deloitte.com/us/en/pages/center-for-board-effectiveness/articles/the-intersection-of-due-diligence-and-governance.html.

Deloitte (2018). *2018 Global Chemical Industry Mergers and Acquisitions Outlook: In Search of Growth*. https://www2.deloitte.com/global/en/pages/manufacturing/articles/global-chemical-industry-m-and-a-outlook.html.

European Chemical Industry Council (2018). *2018 Facts & Figures of the European Chemical Industry*. https://cefic.org/app/uploads/2018/12/Cefic_FactsAnd_Figures_2018_Industrial_BROCHURE_TRADE.pdf.

Exxon Mobil (2018). *2018 Outlook for Energy: A View to 2040.* https://cdn.exxonmobil.com/~/media/global/files/outlook-for-energy/2018/2018-outlook-for-energy.pdf.

Fantke, P. and Ernstoff, A. (2018). LCA of chemicals and chemical products. In *Life Cycle Assessment*. Hauschild, M.Z., Rosenbaum, R.K. and Olsen, S.I. (eds.). Cham: Springer International Publishing. Chapter 31. 783–815. https://doi.org/10.1007/978-3-319-56475-3_31.

Gagnon, M.-A. and Volesky, K.D. (2017). Merger mania: mergers and acquisitions in the generic drug sector from 1995 to 2016. *Globalization and Health* 13(1), 62. https://doi.org/10.1186/s12992-017-0285-x.

Gryzwa, G., Hirschbichler, E., Lorbeer, C. and Weihe, U. (2018). Managing M&A in chemicals: meeting the new challenges, January. *McKinsey&Company*. https://www.mckinsey.com/industries/chemicals/our-insights/managing-m-and-a-in-chemicals-meeting-the-new-challenges Accessed 3 September 2018.

International Chemical Trade Association (2018a). *Global Chemical Consumption Distributed by Third-Party Distributor*. [Figure]. Unpublished. Obtained upon request from ICTA. https://www.icta-chem.org/.

International Chemical Trade Association (2018b). Chemical distribution industry. https://www.icta-chem.org/explore-topics/chemical-distribution-industry. Accessed 3 September 2018.

International Council of Chemical Associations (2015). International Council of Chemical Associations (ICCA) is the worldwide voice of the chemical industry. https://www.icca-chem.org/. Accessed 5 June 2018.

International Energy Agency, International Council of Chemical Associations and Society for Chemical Engineering and Biotechnology (2013). *Technology Roadmap Energy and GHG Reductions in the Chemical Industry via Catalytic Processes*. Paris: International Energy Agency Publications. https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyandGHGReductionsintheChemicalIndustryviaCatalyticProcesses.pdf.

International Labour Organization (2018). *Decent Work and Digitalization in the Chemical and Pharmaceutical Industries Sectoral Policies Department*. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/meetingdocument/wcms_649238.pdf.

Kawaguchi, H., Hasunuma, T., Ogino, C. and Kondo, A. (2016). Bioprocessing of bio-based chemicals produced from lignocellulosic feedstocks. *Current Opinion in Biotechnology* 42, 30-39. https://www.sciencedirect.com/science/article/pii/S0958166916300532.

KPMG (2010). *The Future of the European Chemical Industry*. https://en.calameo.com/read/000046992f8e9d866d03c.

LaVito, A. (2018). J&J shares plunge 10% after report that the company knew for decades about asbestos in baby powder, 14 December. CNBC. https://www.cnbc.com/2018/12/14/johnson--johnson-shares-drop-on-reuters-report-that-the-company-knew-for-decades-of-asbestos-in-its-baby-powder.html. Accessed 30 January 2019.

Levi, P.G. and Cullen, J.M. (2018). Mapping global flows of chemicals: from fossil fuel feedstocks to chemical products. *Environmental Science & Technology*. 52(4), 1725-1734. https://doi.org/10.1021/acs.est.7b04573.

Nicita, A., Ognivtsev, V. and Shirotori, M. (2013). *Global Supply Chains: Trade and Economic Policies for Developing Countries*. Policy Issues in International Trade and Commodities. Ognivtsev, V. (ed.). Geneva: United Nations Conference on Trade and Development. http://unctad.org/en/PublicationsLibrary/itcdtab56_en.pdf.

Niemiec, C. (2016). Reckitt Benckiser apologises for product linked to Korea deaths, 10 May. *Chemical Watch*. https://chemicalwatch.com/asiahub/47110/reckitt-benckiser-apologises-for-product-linked-to-korea-deaths. Accessed 5 September 2018.

Oberle, B., Bringezu, S., Hatfield-Dodds, S., Hellweg, S., Schandl, H., Clement, J., Cabernard, L., Che, N., Chen, D., Droz-Georget, H., Ekins, P., Fischer-Kowalski, M., Flörke, M., Frank, S., Froemelt, A., Geschke, A., Haupt, M., Havlik, P., Hüfner, R., Lenzen, M., Lieber, M., Liu, B., Lu, Y., Lutter, S., Mehr, J., Miatto, A., Newth, D., Oberschelp , C., Obersteiner, M., Pfister, S., Piccoli, E., Schaldach, R., Schüngel, J., Sonderegger, T., Sudheshwar, A., Tanikawa, H., van der Voet, E., Walker, C., West, J., Wang, Z. and Zhu, B. (2019). *Global Resources Outlook 2019: Natural Resources for the Future We Want*. A report of the International Resource Panel. Nairobi: United Nations Environment Programme. http://www.resourcepanel.org/file/1172/download?token=muaePxOQ.

Sarathy, V., Morawietz, M., Gotpagar, J. and Bebiak, J. (2017). *2017 Chemicals Industry Trends*. New York City: Strategy&. https://www.strategyand.pwc.com/media/file/2017-Chemicals-Industry-Trends.pdf.

Tullo, A.H. (2017a). C&EN's global top 50. *Chemical & Engineering News* 95(30), 30-35. https://cen.acs.org/articles/95/i30/CENs-Global-Top-50.html.

Tullo, A.H. (2017b). Women in the chemical industry 2017. *Chemical & Engineering News* 95(36). https://cen.acs.org/articles/95/i36/Women-chemical-industry-2017.html.

United Nations Comtrade (2018). UN Comtrade database: international trade statistics. https://comtrade.un.org/data. Accessed 7 June 2018.

United States Department of Agriculture (2008). *Biobased Products: Market Potential and Projections through 2025*. https://www.usda.gov/oce/reports/energy/BiobasedReport2008.pdf.

Valencia, R.C. (2013). Market outlook: speedy growth for chemicals by 2050, 11 October. *ICIS Chemical Business*. https://www.icis.com/resources/news/2013/10/13/9714353/market-outlook-speedy-growth-for-chemicals-by-2050/. Accessed 8 May 2018.

Wernet, G., Mutel, C., Hellweg, S. and Hungerbühler, K. (2011). The environmental importance of energy use in chemical production. *Journal of Industrial Ecology*. 15(1), 96-107. https://onlinelibrary.wiley.com/doi/full/10.1111/j.1530-9290.2010.00294.x.

World Intellectual Property Organization (2018). Patentscope. https://patentscope.wipo.int/search/en/search.jsf. Accessed 5 June 2018.

World Trade Organization (2018). World Trade Statistical Review 2018. https://www.wto.org/english/res_e/statis_e/wts2018_e/wts2018_e.pdf.

## Chapter 2

American Chemistry Council (2017a). *2017 Elements of the Business of Chemistry*. https://www.americanchemistry.com/2017-Elements-of-the-Business-of-Chemistry.pdf.

American Chemistry Council (2017b). *2017 Year-End Chemical Industry Situation and Outlook*. https://store.americanchemistry.com/Business-of-Chemistry-Situation-and-Outlook.

American Chemistry Council (2018). *2018 Guide to the Business of Chemistry*. https://store.americanchemistry.com/2018GBCPDF.

BCC Research (2017). Nanotechnology sees big growth in products and applications, reports BCC Research, 17 January. https://globenewswire.com/news-release/2017/01/17/906164/0/en/Nanotechnology-Sees-Big-Growth-in-Products-and-Applications-Reports-BCC-Research.html. Accessed 12 April 2018.

BCC Research (2018). Inorganic chemicals manufacturing: global markets to 2022. https://www.bccresearch.com/market-research/chemicals/inorganic-chemicals-manufacturing-global-markets-to-2022-chm106a.html. Accessed 4 September 2018.

Boucher, J. and Friot, D. (2017). *Primary Microplastics in the Oceans: Global Evaluation of Sources*. Lundin, C. G. and Sousa, J. M. de (eds). Gland: International Union for Conservation of Nature and Natural Resources. https://doi.org/10.2305/iucn.ch.2017.01.en.

Brande-Lavridsen, N. (n.d.). *Microplastics in the Freshwater Environment*. Knoxville, TN: University of Tennessee. https://www.epa.gov/sites/production/files/2017-01/documents/microplastics-in-freshwater-environment.pdf.

Brendel, S., Fetter, É., Staude, C., Vierke, L. and Biegel-Engler, A. (2018). Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. *Environmental Sciences Europe*. 30(1), 9. https://doi.org/10.1186/s12302-018-0134-4.

Cayuela, R. And Hagan, A. (2019). *The Chemical Industry Under the 4th Industrial Revolution: The Sustainable, Digital and Citizens One*. Not yet published. Hoboken NJ: Wiley-VCH Verlag GmbH

Cision (2017). Global petrochemicals market analysis & trends – industry forecast to 2025, 1 February. PRNewswire. https://www.prnewswire.com/news-releases/global-petrochemicals-market-analysis--trends---industry-forecast-to-2025-300400745.html. Accessed 5 May 2018.

CropLife International (2015). *One Voice: 2014 Annual Report*. Brussels. https://croplife.org/wp-content/uploads/pdf_files/Annual-report-2014-FINAL-ONLINE.pdf.

Dutta, T., Kim, K.-H., Uchimiya, M., Kwon, E.E., Jeon, B.-H., Deep, A. and Yun, S.-T. (2016). Global demand for rare earth resources and strategies for green mining. *Environmental Research* 150, 182-190. https://doi.org/10.1016/j.envres.2016.05.052.

Elsevier (2017). *R&D Solutions for Chemicals White Paper: Increasing Pressures in Agricultural Chemical R&D Demand New Workflow Solutions*. https://www.elsevier.com/__data/assets/pdf_file/0006/278124/CHEM-RD-WP-Agricultural-Workflow-WEB.pdf.

Essel, R., Engel, L., Carus, M. and Heinrich Ahrens, R. (2015). *Sources of Microplastics Relevant to Marine Protection in Germany*. Werner, S. (ed.). Dessau-Roßlau: German Environment Agency. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_64_2015_sources_of_microplastics_relevant_to_marine_protection_1.pdf.

European Bioplastics and nova-Institute (2018). *Global Production Capacities of Bioplastics 2018-2023*. https://www.european-bioplastics.org/wp-content/uploads/2016/02/Report_Bioplastics-Market-Data_2018.pdf.

European Chemicals Agency (2018). ECHA welcomes improved clarity on nanomaterials in the EU – member states vote to amend REACH annexes, 26 April. https://echa.europa.eu/de/-/echa-welcomes-improved-clarity-on-nanomaterials-in-the-eu-member-states-vote-to-amend-reach-annexes. Accessed 4 September 2018.

European Federation of Pharmaceutical Industries and Associations (2018). *The Pharmaceutical Industry in Europe. Key Data: 2018.* https://efpia.eu/media/361960/efpia-pharmafigures2018_v07-hq.pdf.

EvaluatePharma (2018). *World Preview 2018, Outlook to 2024*. http://www.evaluate.com/thought-leadership/pharma/evaluatepharma-world-preview-2018-outlook-2024.

Food and Agriculture Organization of the United Nations (2017). *World Fertilizer Trends and Outlook to 2020*. http://www.fao.org/3/a-i6895e.pdf.

France, Ministry of Environment Energy and the Sea (2017). Décret n° 2017-291 du 6 mars 2017 relatif aux conditions de mise en œuvre de l’interdiction de mise sur le marché des produits cosmétiques rincés à usage d’exfoliation ou de nettoyage comportant des particules plastiques solides et des bâtonnets ouatés à usage domestique dont la tige est en plastique. https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000034154540&dateTexte&categorieLien=id. Accessed 8 September 2018.

Fthenakis, V. (n.d.). *Could CdTe PV Modules Pollute the Environment*? Upton, NY:Brookhaven National Laboratory. https://www.bnl.gov/pv/files/pdf/art_164.pdf.

Galloway, T.S. (2015). Micro- and nano-plastics and human health. In *Marine Anthropogenic Litter*. Cham: Springer International Publishing. 343-366. https://doi.org/10.1007/978-3-319-16510-3_13.

Gautam, A. and Pan, X. (2016). The changing model of big pharma: impact of key trends. *Drug Discovery Today* 21(3), 379-384. https://doi.org/10.1016/j.drudis.2015.10.002.

Geyer, R., Jambeck, J.R. and Law, K.L. (2017). Production, use, and fate of all plastics ever made. *Science Advances* 3(7), 1-5. https://doi.org/10.1126/sciadv.1700782.

Gibb, R., Bunce, M., Mee, L.D. and Ro, L.D. (2017). Sources, fate and effects of microplastics in the marine environment: a global assessment. *Global Change Biology* 9, 10. https://doi.org/10.13140/RG.2.1.3803.7925.

Government of Canada (2019a). Regulations adding perfluorooctane sulfonate and its salts to the virtual elimination list (SOR/2009-15), 26 March. https://pollution-waste.canada.ca/environmental-protection-registry/regulations/view?Id=97. Accessed 28 March 2019.

Government of Canada (2019b). Regulations amending the prohibition of certain toxic substances regulations, 2012 (for the addition of 5 substances) (SOR/2016-252), 26 March. https://pollution-waste.canada.ca/environmental-protection-registry/regulations/view?Id=131. Accessed 28 March 2019.

Guberman, D.E. (2017). *2015 Minerals Yearbook: Lead [Advance Release]*. Reston, VA: United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/lead/myb1-2015-lead.pdf.

IHS Markit (2017). Flame retardants - specialty chemicals update program. https://ihsmarkit.com/products/chemical-flame-retardants-scup.html. Accessed 2 May 2018.

Informa (2017). *Global Agribusiness Annual 2017: Towards a Sustainable Future*. Horseman, C. and McCary, K. (eds). London: Philip Solomon. https://agribusinessintelligence.informa.com/global-agribusiness-annual-2017/.

Inshakova, E. and Inshakov, O. (2017). World market for nanomaterials: structure and trends. *MATEC Web of Conferences* 129(02013), 1-5. https://doi.org/10.1051/matecconf/201712902013.

International Federation of Pharmaceutical Manufacturers and Associations (2017). *The Pharmaceutical Industry and Global Health: Facts and Figures 2017.* https://www.ifpma.org/wp-content/uploads/2017/02/IFPMA-Facts-And-Figures-2017.pdf.

International Fertilizer Association (2018). *Fertilizer Outlook 2018-2022*. https://www.fertilizer.org/images/Library_Downloads/2018_IFA_Annual_Conference_Berlin_PIT_AG_Fertilizer_Outlook.pdf.

International Lead and Zinc Study Group (2018). Lead and zinc statistics. http://www.ilzsg.org/static/statistics.aspx. Accessed 22 May 2018.

International Lead and Zinc Study Group (2019). *Lead Factbook*. Forthcoming report. http://www.ilzsg.org/static/home.aspx.

International Lead Association (2018). Lead recycling. https://www.ila-lead.org/lead-facts/lead-recycling. Accessed 4 September 2018.

Janshekar, H., Rizvi, S.Q.A., Inoguchi, Y. and Ma, X. (2015). *Specialty Chemicals Update Program: Surfactants*. London: IHS Markit. https://chemstore.ihsmarkit.com/products/scup-surfactants?utm_source=ihsmarkit&utm_medium=referral&utm_campaign=PC10539.

Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (n.d.). *Microplastics in the Ocean: Sources, Fate and Effects.* http://www.gesamp.org/site/assets/files/1720/24472_gesamp_leaflet_pq.pdf.

Kazan-Allen, L. (2017). Brazil bans asbestos! 1 December. *International Ban Asbestos Secretariat*. http://www.ibasecretariat.org/lka-brazil-bans-asbestos.php. Accessed 2 February 2018.

Kazan-Allen, L. (2018). Current asbestos bans, 23 October. *International Ban Asbestos Secretariat*. http://ibasecretariat.org/alpha_ban_list.php. Accessed 29 November 2018.

Mateo-Sagasta, J., Zadeh, S.M. and Turral, H. (2017). *Water Pollution from Agriculture: A Global Review*. Rome: Food and Agriculture Organization. http://www.fao.org/3/a-i7754e.pdf.

McGovern, B. (2018). Pharmaceutical industry overview: top international regions for drug companies, 12 March. *Pharmaceutical Investing News*. https://investingnews.com/daily/life-science-investing/pharmaceutical-investing/top-pharmaceutical-regions/. Accessed 22 May 2018.

Oliver, E. (2018). Growing importance of China and India in the global crop protection market. *Agribusiness Intelligence, Informa*. https://agribusinessintelligence.informa.com/resources/product-content/growing-importance-of-china-and-india-in-the-global-crop-protection-market. Accessed 15 November 2018.

Organisation for Economic Co-operation and Development (2013). *OECD/UNEP Global PFC Group, Synthesis Paper on Per- and Polyfluorinated Chemicals (PFCs)*. https://www.oecd.org/env/ehs/risk-management/PFC_FINAL-Web.pdf.

Organisation for Economic Co-operation and Development (2018a). *Toward a Comprehensive Global Database of Per-and Polyfluoroalkyl Substances (PFASs). Summary Report on Updating the OECD 2007 List of Per- and Polyfluoroalkyl Substances (PFASs).* http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en.

Organisation for Economic Co-operation and Development (2018b). Safety of manufactured nanomaterials. http://www.oecd.org/science/nanosafety/. Accessed 1 January 2019.

Pavel, C.C., Lacal-Arántegui, R., Marmier, A., Schüler, D., Tzimas, E., Buchert, M., Jenseit, W. and Blagoeva, D. (2017). Substitution strategies for reducing the use of rare earths in wind turbines. *Resources Policy* 52, 349-357. https://doi.org/10.1016/j.resourpol.2017.04.010.

Phillips McDougal (2018). *Evolution of the Crop Protection Industry Since 1960.* Midlothian: Informa. https://agribusinessintelligence.informa.com/~/media/informa-shop-window/agri/images/sample-content/reports/pmd_evolution_of_the_crop_protection_industry.pdf.

Plastics Europe (2018). *Plastics – the Facts 2018: An Analysis of European Production, Demand and Waste Data.* https://www.plasticseurope.org/application/files/6315/4510/9658/Plastics_the_facts_2018_AF_web.pdf.

Plotkin, J.S. (2015). The propylene gap: how can it be filled? 14 September. *American Chemical Society*. https://www.acs.org/content/acs/en/pressroom/cutting-edge-chemistry/the-propylene-gap-how-can-it-be-filled.html. Accessed 2 July 2018.

Pravettoni, R. (2018). *Global plastic production and future trends*. [Graph]. GRID-Arendal. http://www.grida.no/resources/6923. Accessed 10 October 2018.

Rothfeder, J. (2017). The big next technology could be nanomaterials, 26 July. *Strategy+business*. https://www.strategy-business.com/article/The-Next-Big-Technology-Could-Be-Nanomaterials. Accessed 3 September 2018.

Secretariat of the Stockholm Convention (2008). Chemicals proposed for listing under the Convention. http://chm.pops.int/TheConvention/ThePOPs/ChemicalsProposedforListing/tabid/2510/Default.aspx. Accessed 22 May 2018.

Smith, K., Glauser, J. and Eramo, M. (2017). *Chemical Economics Handbook: Petrochemical Industry Overview. Report and Market Outlook.* IHS Markit. https://chemstore.ihsmarkit.com/products/ceh-petrochemical-industry-overview?utm_source=ihsmarkit&utm_medium=referral&utm_campaign=PC10539.

Tolcin, A.C. (2018). *2016 Minerals Yearbook: Cadmium [Advance Release]*. Reston, VA: United States Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/cadmium/myb1-2016-cadmi.pdf.

Transparency Market Research (2016). Africa lead acid batteries market to exhibit 5.3% CAGR 2015-2021, driven by rising demand for automobiles, June. https://www.transparencymarketresearch.com/pressrelease/africa-lead-acid-battery-industry.htm. Accessed 4 September 2018.

Transparency Market Research (n.d.). Pesticides market revenue, size, share, growth, trends and industry forecast 2017-2025. https://www.transparencymarketresearch.com/global-pesticides-market.html. Accessed 5 May 2018.

United Nations Environment Programme (2015). *Report by the United Nations Environment Programme on Progress in the Implementation of the Global Alliance for the Development and Deployment of Products, Methods and Strategies as Alternatives to DDT for Disease Vector Control (Global Alliance on DDT)*. Geneva: Secretariat of the Stockholm Convention. http://chm.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP7/tabid/4251/mctl/ViewDetails/EventModID/870/EventID/543/xmid/13075/Default.aspx.

United Nations Environment Programme (2016a). *Consolidated Assessment of Efforts Made Toward the Elimination of Polychlorinated Biphenyls*. https://wedocs.unep.org/bitstream/handle/20.500.11822/13664/Consolidated%20PCB%20Assessment_2016.pdf.

United Nations Environment Programme (2016b). *Marine Plastic Debris and Microplastics – Global Lessons and Research to Inspire Action and Guide Policy Change*. http://wedocs.unep.org/handle/20.500.11822/7720.

United Nations Environment Programme (2017). *Global Mercury Supply, Trade and Demand*. http://wedocs.unep.org/bitstream/handle/20.500.11822/21725/global_mercury.pdf?sequence=1&isAllowed=y.

United Nations Environmental Program (2018). *Update on the Global Status of Legal Limits on Lead in Paint: September 2018*. https://wedocs.unep.org/bitstream/handle/20.500.11822/26481/Lead_Status_201809.pdf?sequence=1&isAllowed=y

United States Environmental Protection Agency (2017a). Fact sheet: assessing risks from flame retardants. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-assessing-risks-flame-retardants. Accessed 4 September 2018.

United States Environmental Protection Agency (2017b). Control of nanoscale materials under the toxic substances control act. https://www.epa.gov/reviewing-new-chemicals-under-toxic-substances-control-act-tsca/control-nanoscale-materials-under. Accessed 14 August 2018.

United States Food and Drug Administration (2018). What are 'biologics' questions and answers, 2 June. *Center for Biologics Evaluation and Research*. https://www.fda.gov/aboutfda/centersoffices/officeofmedicalproductsandtobacco/cber/ucm133077.htm. Accessed 4 September 2018.

United States Geological Survey (2016). Asbestos. In *Mineral Commodity Summaries 2016*. 28-29. https://minerals.usgs.gov/minerals/pubs/commodity/asbestos/mcs-2016-asbes.pdf.

United States Geological Survey (2018a). *Mineral Commodity Summaries 2018*. https://minerals.usgs.gov/minerals/pubs/mcs/2018/mcs2018.pdf.

United States Geological Survey (2018b). Minerals information: asbestos - statistics and information, 15 May. https://minerals.usgs.gov/minerals/pubs/commodity/asbestos/. Accessed 4 February 2019.

United States National Oceanic and Atmospheric Administration (2018). What are microplastics? 25 June. https://oceanservice.noaa.gov/facts/microplastics.html. Accessed 6 September 2018.

Wietlisbach, S. and Gao, A. (2016). *Chemical Economics Handbook: Rare Earth Minerals & Products*. London: IHS Markit. https://chemstore.ihsmarkit.com/products/ceh-rare-earth-minerals-and-products?utm_source=ihsmarkit&utm_medium=referral&utm_campaign=PC10539.

Zhang, E., Greiner, E., Janshekar, H. and Kumamoto, T. (2016). *Chemical Economics Handbook: Fluoropolymers*. London: IHS Markit. https://ihsmarkit.com/products/fluoropolymers-chemical-economics-handbook.html.

Zion Research (2016). Global plastic packaging market – industry analysis, size, share, trends, segment and forecast 2014-2020. http://www.marketresearchstore.com/report/plastic-packaging-market-z47941. Accessed 3 May 2018.

## Chapter 3

Accenture (2017). *Taking the European Chemical Industry into the Circular Economy: Executive Summary*. https://www.accenture.com/t20170314T154717Z__w__/us-en/_acnmedia/PDF-45/Accenture-CEFIC-Report-Exec-Summary.pdf#zoom=50.

Access to Medicine Foundation (2018). *Antimicrobial Resistance Benchmark 2018: First Independent Assessment of Pharmaceutical Company Action on AMR*. https://www.amrbenchmark.org/media/uploads/downloads/5bc5edd8367eb_Antimicrobial-Resistance-Benchmark-2018.pdf.

African Development Bank,Organisation for Economic Co-operation and Development and United Nations Development Programme (2017). *African Economic Outlook 2017: Entrepreneurship and Industrialisation*. Paris: OECD publishing. http://dx.doi.org/10.1787/aeo-2017-en.

Agarwal, R., Chandrasekaran, S. and Sridhar, M. (2016). Imagining construction's digital future, June. *McKinsey & Company*. https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future. Accessed 18 July 2018.

Alshahri, F. (2017). Heavy metal contamination in sand and sediments near to disposal site of reject brine from desalination plant, Arabian Gulf: Assessment of environmental pollution. *Environmental Science and Pollution Research* 24(2), 1821-1831. https://doi.org/10.1007/s11356-016-7961-x.

Aman, M.M., Solangi, K.H., Hossain, M.S., Badarudin, A., Jasmon, G.B., Mokhlis, H., Bakar, A.H.A. and Kazi, S.N. (2015). A review of safety, health and environmental (SHE) issues of solar energy system. *Renewable and Sustainable Energy Reviews*. 41, 1190-1204. https://doi.org/10.1016/J.RSER.2014.08.086.

American Chemical Society (2015). *How Industrial Applications in Green Chemistry are Changing our World*. https://www.acs.org/content/dam/acsorg/membership/acs/benefits/extra-insights/green-chemistry-applications.pdf.

Arbesman, S. (2016). *Overcomplicated: Technology at the Limits of Comprehension*. New York, NY: Penguin. https://www.penguinrandomhouse.com/books/317781/overcomplicated-by-samuel-arbesman/9780143131304/.

Baldé, C.P., Forti V., Gray, V., Kuehr, R. and Stegmann, P. (2017). *The Global E-Waste Monitor 2017*. United Nations University. Bonn, Geneva and Vienna: United Nations University, International Telecommunication Union and the International Solid Waste Association . https://collections.unu.edu/eserv/UNU:6341/Global-E-waste_Monitor_2017__electronic_single_pages_.pdf.

Bamber, P., Frederick, S. and Gereffi, G. (2016). *The Philippines in the Chemical Global Value Chain*. Durham, NC: Duke University. http://industry.gov.ph/wp-content/uploads/2017/08/The-Philippines-in-the-Chemical-Global-Value-Chain.pdf.

Bárcena, A., Prado, A., Alatorre, E., Ferrer, J., Javier Gómez, J., Lennox, J., Reyes, O., Sánchez, L., de Miguel, C., Gomes, C., Jordán, R., Kissoon, E., Martínez, K., Montero, L., Olivares, J., Peralta, L., Pereira, M. and Thorne, E. (2015). *The Economics of Climate Change in Latin America and the Caribbean: Paradoxes and Challenges of Sustainable Development*. Santiago: United Nations. https://repositorio.cepal.org/bitstream/handle/11362/37311/S1420655_en.pdf.

Barra. R. and Leonard, S.A. (2018). *Plastics and the Circular Economy.* Scientific and Technical Advisory Panel to the Global Environment Facility https://www.thegef.org/sites/default/files/publications/PLASTICS%20for%20posting.pdf.

BASF (2013). The new operating division performance polymers, 25 June. https://www.basf.com/en/company/news-and-media/news-releases/2013/06/p-13-292.html. Accessed 5 September 2018.

Berg, A., Hedrich, S. and Russo, B. (2015). East Africa: the next hub for apparel sourcing? August. McKinsey & Company. https://www.mckinsey.com/industries/retail/our-insights/east-africa-the-next-hub-for-apparel-sourcing. Accessed 2 September 2018.

Berger, R., Henzelmann, T., Büchele, R., Andrae, P. and Wiedemann, A. (2018). *GreenTech Made in Germany 2018: Environmental Technology Atlas for Germany*. Parker, N. and Veth, S. (eds.). Berlin: German Ministry of the Environment, Nature Conservation and Nuclear Safety. https://www.bmu.de/fileadmin/Daten_BMU/Pools/Broschueren/greentech_2018_en_bf.pdf.

Burkhardt, M., Zuleeg, S., Vonbank, R., Schmid, P., Hean, S., Lamani, X., Bester, K. and Boller, M. (2011). Leaching of additives from construction materials to urban storm water runoff. *Water Science & Technology* 63(9), 1974-1982. https://doi.org/10.2166/wst.2011.128.

Business Wire (2016). Global biological crop protection (bio-pesticide) market (2016-2021): by type, application, end user, region & country - research and markets, 15 December. *Research and Markets*. https://www.businesswire.com/news/home/20161215005498/en/Global-Biological-Crop-Protection-Bio-Pesticide-Market-2016-2021.

Cadena, A., Remes, J., Grosman, N. and de Oliveira, A. (2017). *Where Will Latin America's Growth Come From?* McKinsey & Company. https://www.mckinsey.com/~/media/mckinsey/featured%20insights/employment%20and%20growth/how%20to%20counter%20three%20threats%20to%20growth%20in%20latin%20america/mgi-discussion-paper-where-will-latin-americas-growth-come-from-april-2017.ashx.

Carvalho, F.P. (2017). Pesticides, environment, and food safety. *Food and Energy Security*. 6(2), 48-60. https://doi.org/10.1002/fes3.108.

Cayuela, R. and Hagan, A. (2019). *The Chemical Industry Under the 4th Industrial Revolution: The Sustainable, Digital and Citizens One*. Not yet published. Hoboken, NJ: Wiley-VCH Verlag GmbH.

Changing Markets Foundation and Ecostorm (2016). *Superbugs in the Supply Chain: How Pollution from Antibiotics Factories in India and China is Fuelling the Global Rise of Drug-Resistant Infections*. https://epha.org/wp-content/uploads/2016/10/Superbugsinthesupplychain_CMreport.pdf.

Changing Markets Foundation and Nordea (2018). *Hyderabad's Pharmaceutical Pollution Crisis: Heavy Metal and Solvent Contamination at Factories in a Major Indian Drug Manufacturing Hub*. https://changingmarkets.org/wp-content/uploads/2018/01/CM-HYDERABAD-s-PHARMACEUTICAL-POLLUTION-CRISIS-FINAL-WEB-SPREAD.pdf.

Daniell, W.E., Van Tung, L., Wallace, R.M., Havens, D.J., Karr, C.J., Bich Diep, N., Croteau, G.A., Beaudet, N.J. and Duy Bao, N. (2015). Childhood lead exposure from battery recycling in Vietnam. *BioMed Research International*. 2015, 1-10. https://doi.org/10.1155/2015/193715.

DeGusta, M. (2012). Are smart phones spreading faster than any technology in human history, 9 May. *MIT Technology Review*. https://www.technologyreview.com/s/427787/are-smart-phones-spreading-faster-than-any-technology-in-human-history/. Accessed 9 May 2018.

Delcour, I., Spanoghe, P. and Uyttendaele, M. (2015). Literature review: Impact of climate change on pesticide use. *Food Research International* 68, 7-15. https://doi.org/10.1016/j.foodres.2014.09.030.

Deloitte and German Chemical Industry Association (2017). *Chemistry 4.0: Growth Through Innovation in a Transforming World*. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/consumer-industrial-products/gx-chemistry%204.0-full-report.pdf.

DHL (2016). *The 21st Century Spice Trade: A Guide to the Cross-border E-commerce Opportunity*. http://www.dhl.com/content/dam/downloads/g0/press/publication/g0_dhl_express_cross_border_ecommerce_21st_century_spice_trade.pdf

Dugarova, E. and Gülasan, N. (2017). *Global Trends: Challenges and Opportunities in the Implementation of the Sustainable Development Goals*. New York, NY and Geneva: United Nations Development Programme; United Nations Research Institute for Social Development. http://www.undp.org/content/undp/en/home/librarypage/sustainable-development-goals/global-trends--challenges-and-opportunities-in-the-implementatio.html.

Eder-Hansen, J., Chalmer, C., Tärneberg, S., Tochtermann, T., Seara, J., Boger, S., Theelen, G., Schwarz, S., Kristensen, L. and Jäger, K. (2017). *Pulse of the Fashion Industry*. Copenhagen and Boston, MA: Global Fashion Agenda & Boston Consulting Group. https://globalfashionagenda.com/wp-content/uploads/2017/05/Pulse-of-the-Fashion-Industry_2017.pdf.

Ellen MacArthur Foundation (2017). *A New Textiles Economy: Redesigning Fashion's Future*. Conker house publishing. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report_Updated_1-12-17.pdf.

Ericson, B., Landrigan, P., Taylor, M.P., Frostad, J., Caravanos, J., Keith, J. and Fuller, R. (2016). The global burden of lead toxicity attributable to informal used lead-acid battery sites. *Annals of Global Health*. 82(5), 686-699. https://doi.org/10.1016/J.AOGH.2016.10.015.

Ernst & Young (2016). *The Upside of Disruption: Megatrends Shaping 2016 and Beyond*. https://cdn.ey.com/echannel/gl/en/issues/business-environment/2016megatrends/001-056_EY_Megatrends_report.pdf.

European Chemical Industry Council (2018). *2018 Facts & Figures of the European Chemical Industry*. https://cefic.org/app/uploads/2018/12/Cefic_FactsAnd_Figures_2018_Industrial_BROCHURE_TRADE.pdf.

European Chemicals Agency (2018). *Strategy to Promote Substitution to Safer Chemicals Through Innovation*. https://doi.org/10.2823/99862.

European Environment Agency (2015). *The European Environment — State and Outlook 2015: Assessment of Global Megatrends*. https://doi.org/10.2800/126936.

European Federation of Pharmaceutical Industries and Associations (2016). *ECO-Pharmaco-Stewardship (EPS): A Holistic Environmental Risk Management Program.* https://www.efpia.eu/media/25628/eps-a-holistic-environmental-risk-management-program.pdf

European Innovation Partnership for Agricultural Productivity and Sustainability (2017). *EIP-AGRI Seminar: Digital Innovation Hubs for Agriculture*. https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_seminar_digital_innovation_hubs_final_report_2017_en.pdf.

Food and Agriculture Organization of United Nations (2017). *World Fertilizer Trends and Outlook to 2020*. http://www.fao.org/3/a-i6895e.pdf.

Food and Agriculture Organization for the United Nations (2018). FAOSTAT: pesticides. http://www.fao.org/faostat/en/#data/EP/visualize. Accessed 28 November 2018.

Frost & Sullivan (2014). *World's Top Global Mega Trends To 2025 and Implications to Business, Society and Cultures*. https://www.smeportal.sg/content/dam/smeportal/resources/Business-Intelligence/Trends/Global%20Mega%20Trends_Executive%20Summary_FROST%20%26%20SULLIVAN.pdf.

Gaines, L. (2014). The future of automotive lithium-ion battery recycling: charting a sustainable course. *Sustainable Materials and Technologies* 1-2, 2-7. https://doi.org/10.1016/J.SUSMAT.2014.10.001.

García, D. and Marín, D. (2016). Dirty business: Africa's unregulated lead battery smelting, 3 March. *Ecologist*. https://theecologist.org/2016/mar/03/dirty-business-africas-unregulated-lead-battery-smelting. Accessed 5 September 2018.

Gathuru, I.M., Buchanich, J.M., Marsh, G.M. and Dolan, D.G. (2015). Health hazards in the pharmaceutical industry. *Pharmaceutical Regulatory Affairs*. 04(03), 1-15. https://doi.org/10.4172/2167-7689.1000145.

Geisler, S. (2018). Digitisation in agriculture - from precision farming to farming 4.0, 9 April. *Bioeconomy BW*. https://www.biooekonomie-bw.de/en/articles/dossiers/digitisation-in-agriculture-from-precision-farming-to-farming-40/. Accessed 8 February 2019.

Global Construction Perspectives and Oxford Economics (2015). *Global Construction 2030: A Global Forecast for the Construction Industry to 2030*. https://gcp.global/uk/products/global-construction-2030.

Global Manufacturing Industry Group (2010). *The Chemical Multiverse - Preparing for Quantum Changes in the Global Chemical Industry*. London: Deloitte. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Manufacturing/gx_The%20chemical%20multiverse_12_2_2010.pdf.

Global Manufacturing Industry Group (2011). *End Market Alchemy: Expanding Perspectives to Drive Growth in the Global Chemical Industry*. London: Deloitte. https://www2.deloitte.com/be/en/pages/manufacturing/articles/end-market-alchemy-drive-chemical-industry-growth.html.

Global Market Insights (2017). Construction chemicals market size - industry share report 2024, February. https://www.gminsights.com/industry-analysis/construction-chemicals-market. Accessed 6 May 2018.

Grand View Research (2017). Agrochemicals market worth $308.92 billion by 2025 | CAGR: 4.1%, June. https://www.grandviewresearch.com/press-release/global-agrochemicals-market. Accessed 7 June 2018.

Grannas, A.M., Bogdal, C., Hageman, K.J., Halsall, C., Harner, T., Hung, H., Kallenborn, R., Klán, P., Klánová, J., Macdonald, R.W., Meyer, T. and Wania, F. (2013). The role of the global cryosphere in the fate of organic contaminants. *Atmospheric Chemistry and Physics* 13, 3271-3305. https://doi.org/10.5194/acp-13-3271-2013.

Green, D. (2016). The world's top 100 economies: 31 countries; 69 corporations, 20 September. *World Bank*. https://blogs.worldbank.org/publicsphere/world-s-top-100-economies-31-countries-69-corporations. Accessed 12 May 2018.

Haefliger, P., Mathieu-Nolf, M., Lociciro, S., Ndiaye, C., Coly, M., Diouf, A., Faye, A.L., Sow, A., Tempowski, J., Pronczuk, J., Junior, A.P.F., Bertollini, R. and Neira, M. (2009). Mass lead intoxication from informal used lead-acid battery recycling in Dakar, Senegal. *Environmental Health Perspectives*. 117(10), 1535-1540. https://doi.org/10.1289/ehp.0900696.

Hahladakis, J., Costas, V., Roland, W., Iacovidou, I. and Purnell, P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. *Journal of Hazardous Materials* 344, 179-199. https://doi.org/10.1016/j.jhazmat.2017.10.014.

Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D. and de Kroon, H. (2017). More than 75 per cent decline over 27 years in total flying insect biomass in protected areas. *Public Library of Science ONE*. 12(10), 1-21. https://doi.org/10.1371/journal.pone.0185809.

Hannon, E., McKerracher, C., Orlandi, I. and Ramkumar, S. (2016). An integrated perspective on the future of mobility, October. *McKinsey & Company*. https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/an-integrated-perspective-on-the-future-of-mobility. Accessed 5 September 2018.

Health Care Without Harm Europe (2018). *The Environmental Impact of Pharmaceuticals Manufacturing: How Does Industry Address its Own Waste?* http://saferpharma.org/wp-content/uploads/2018_PharmaceuticalIndustryReport_WEB.pdf.

Hoeppe, P. (2016). Trends in weather related disasters: Consequences for insurers and society. *Weather and Climate Extremes* 11, 70-79. https://doi.org/10.1016/J.WACE.2015.10.002.

Huang, B., Jin, M., Yuhong, W., Mohammad, L.N. and Liu, X. (eds) (2017). Sustainable road paving: materials, design, construction, and maintenance. *Journal of Cleaner Production*. https://www.sciencedirect.com/journal/journal-of-cleaner-production/special-issue/10Q9D5Q33JP.

International Council of Chemical Associations (2017). *Avoiding Greenhouse Gas Emissions: The Essential Role of Chemicals - Quantifying the Global Potential*. www.icca-chem.org/wp-content/uploads/2017/11/Ecofys-tryptique_PP.pdf.

International Energy Agency (2017). World energy outlook 2017. https://www.iea.org/weo2017/. Accessed 5 September 2018.

International Lead and Zinc Study Group (2019). *Lead Factbook*. Forthcoming report. http://www.ilzsg.org/static/home.aspx.

Jaakkola, J.J.K. and Knight, T.L. (2008). The role of exposure to phthalates from polyvinyl chloride products in the development of asthma and allergies: a systematic review and meta-analysis. *Environmental Health Perspectives*. 116(7), 845-853. https://doi.org/10.1289/ehp.10846.

Julander, A., Lundgren, L., Skare, L., Grandér, M., Palm, B., Vahter, M. and Lidén, C. (2014). Formal recycling of e-waste leads to increased exposure to toxic metals: an occupational exposure study from Sweden. *Environment International*. 73, 243-251. https://doi.org/10.1016/J.ENVINT.2014.07.006.

Kadajji, V.G. and Betageri, G. V. (2011). Water soluble polymers for pharmaceutical applications. *Polymers* 3(4), 1972-2009. https://doi.org/10.3390/polym3041972

Kanchongkittiphon, W., Mendell, M.J., Gaffin, J.M., Wang, G. and Phipatanakul, W. (2015). Indoor environmental exposures and exacerbation of asthma: an update to the 2000 review by the institute of medicine. *Environmental Health Perspectives*. 123(1), 6-20. http://dx.doi.org/10.1289/ehp.1307922.

Kant, R. (2012). Textile dyeing industry an environmental hazard. *Natural Science*. 4(1), 22-26. http://dx.doi.org/10.4236/ns.2012.41004.

Kharas, H. (2017). *The Unprecedented Expansion of the Global Middle Class: An Update*. Washington, DC: Brookings Institution. https://www.brookings.edu/wp-content/uploads/2017/02/global_20170228_global-middle-class.pdf.

Kharas, H. and Hamel, K. (2018). A global tipping point: half the world is now middle class or wealthier, 27 September. *The Brookings Institution*. https://www.brookings.edu/blog/future-development/2018/09/27/a-global-tipping-point-half-the-world-is-now-middle-class-or-wealthier/?utm_campaign=Brookings%20Global%20Connection&utm_source=hs_email&utm_medium=email&utm_content=66338119. Accessed 8 February 2019.

Khokhar, T. (2017). Chart: Globally, 70% of freshwater is used for agriculture, 22 March. *The Data Blog, The World Bank*. https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture. Accessed 8 February 2019.

Kim, J., Ko, Y. and Lee, W. (2013). Depressive symptoms and severity of acute occupational pesticide poisoning among male farmers. *Occupational and Environmental Medicine* 70(5), 303-309. https://doi.org/10.1136/oemed-2012-101005.

Klei, A., Moder, M., Stockdale, O., Weihe, U. and Winkler, G. (2017). Digital in chemicals: from technology to impact, July. https://www.mckinsey.com/industries/chemicals/our-insights/digital-in-chemicals-from-technology-to-impact. Accessed 20 September 2018.

KPMG (2014): *Future State 2030: The Global Megatrends Shaping Governments*. https://assets.kpmg.com/content/dam/kpmg/pdf/2014/02/future-state-2030-v3.pdf.

KPMG (2017). *Global Transport: Transport Tracker – Market Trends and Views*. https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2017/12/transport-tracker.PDF.

Kumpf, R.J., Eliaz, S. and Aldred, T. (2018). *Making the Future of Mobility: Chemicals and Specialty Materials in Electric, Autonomous, and Shared Vehicles*. Budman, M. and Khan, A. (eds). Deloitte. https://www2.deloitte.com/content/dam/insights/us/articles/4190_FoM-chemicals/DI_Making-FoM.pdf.

Larcher, D. and Tarascon, J.-M. (2015). Towards greener and more sustainable batteries for electrical energy storage. *Nature Chemistry*. 7(1), 19-29. https://doi.org/10.1038/nchem.2085.

Larsson, D.G.K. (2014). Pollution from drug manufacturing: review and perspectives. *Philosophical Transactions of the Royal Society B. Biological Sciences* 369(1656), 1-7. https://doi.org/10.1098/rstb.2013.0571.

Liu, C.-W., Sung, Y., Chen, B.-C. and Lai, H.-Y. (2014). Effects of nitrogen fertilizers on the growth and nitrate content of lettuce (Lactuca Sativa L.). *International Journal of Environmental Research and Public Health*. 11(4), 4427-4440. https://doi.org/10.3390/ijerph110404427.

Liu, P. and Barlow, C.Y. (2017). Wind turbine blade waste in 2050. *Waste Management*. 62, 229-240. https://doi.org/10.1016/J.WASMAN.2017.02.007.

Lundgren, K. (2012). *The Global Impact of E-Waste: Addressing the Challenge*. Geneva: International Labour Organization. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_196105.pdf.

Lv, W., Wang, Z., Cao, H., Sun, Y., Zhang, Y. and Sun, Z. (2018). A critical review and analysis on the recycling of spent lithium-ion batteries. *ACS Sustainable Chemistry & Engineering*. 6(2), 1504-1521. https://doi.org/10.1021/acssuschemeng.7b03811.

McNair, C. (2017). *Worldwide Retail and Ecommerce Sales: eMarketer's Estimates for 2016–2021*. New York, NY: eMarketer. https://www.emarketer.com/Report/Worldwide-Retail-Ecommerce-Sales-eMarketers-Estimates-20162021/2002090.

McWilliams, A. (2016). Electronic chemicals and materials: the global market. *BCC Research.* https://www.bccresearch.com/market-research/semiconductor-manufacturing/electronic-chemicals-materials-markets-report-smc043d.html. Accessed 5 September 2018.

Mordor Intelligence (2018). Construction chemicals market - segmented by product type (concrete admixture, surface treatments, repair and rehabilitation, protective coatings, industrial flooring, water proofing, adhesives, sealants, grouts and anchors, cement grinding aids), end-user industry, and geography - growth, trends and forecasts (2019 - 2024), October. https://www.mordorintelligence.com/industry-reports/global-construction-chemicals-market-industry. Accessed 18 February 2019.

Munich Re (2017). The year in figures, 27 March. https://www.munichre.com/topics-online/en/2017/topics-geo/overview-natural-catastrophe-2016. Accessed 9 September 2018.

National Intelligence Council (2017): *Global Trends: Paradox of Progress*. https://www.dni.gov/files/documents/nic/GT-Full-Report.pdf.

Nimpuno, N. and Scruggs, C. (2011). *Information on Chemicals in Electronic Products: A Study of Needs, Gaps, Obstacles and Solutions to Provide and Access Information on Chemicals in Electronic Products Information on Chemicals in Electronic Products*. Copenhagen: Nordic Council of Ministers. http://chemsec.org/app/uploads/2016/04/110629_Information_on_Chemicals_in_Electronic_Products.pdf.

Nordea (2016). *Impacts of Pharmaceutical Pollution on Communities and Environment in India*. http://changingmarkets.org/wp-content/uploads/2017/07/2016-04_pharma-pollution-in-India_small_web_spread.pdf.

Organisation for Economic Co-operation and Development (2016). *OECD Science, Technology and Innovation Outlook 2016*. http://dx.doi.org/10.1787/sti_in_outlook-2016-en.

Organisation for Economic Co-operation and Development (2018). *Global Forum on Agriculture: How Digital Technologies are Impacting the Way We Grow and Distribute Food*. www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/CA/GF(2018)1&docLanguage=En.

Organisation for Economic Co-operation and Development and International Transport Forum (2017). *ITF Transport Outlook 2017*. http://dx.doi.org/10.1787/9789282108000-en.

Owens, B. (2015). Pharmaceuticals in the environment: a growing problem. *The Pharmaceutical Journal*. 294(7850). https://doi.org/10.1211/PJ.2015.20067898.

Perkins, D.N., Brune Drisse, M.-N., Nxele, T. and Sly, P.D. (2014). E-waste: a global hazard. *Annals of Global Health*. 80(4), 286-295. https://doi.org/10.1016/j.aogh.2014.10.001.

Plastics Europe (2012). *Plastics. Architects of Modern and Sustainable Buildings.* https://www.plasticseurope.org/application/files/6515/1714/0577/bc_flyer111212.pdf.

Prasad, E. and Sinha, B. (2016). Green building materials market by product type (exterior products, interior products, building systems, solar products and others), application (residential buildings and non-residential buildings) - global opportunity analysis and industry forecast, 2014-2022. *Allied Market Research*. https://www.alliedmarketresearch.com/green-buildings-materials-market. Accessed 5 September 2018.

PricewaterhouseCoopers (2017). *The Long View: How Will the Global Economic Order Change by 2050?* https://www.pwc.com/gx/en/world-2050/assets/pwc-world-in-2050-summary-report-feb-2017.pdf.

PricewaterhouseCoopers (2018). *Five Trends Transforming the Automotive Industry*. https://www.pwc.at/de/publikationen/branchen-und-wirtschaftsstudien/eascy-five-trends-transforming-the-automotive-industry_2018.pdf.

Produce Marketing Association Research (2017). What's driving continued growth in organic produce? 5 December. https://www.pma.com/content/articles/2017/10/whats-driving-continued-growth-in-organic-produce. Accessed 5 September 2018.

Pucher, J. and Buehler, R. (2017). Cycling towards a more sustainable transport future. *Transport Reviews*. 37(6), 689-694. https://doi.org/10.1080/01441647.2017.1340234.

Pure Earth and Green Cross Switzerland (2016). *World's Worst Pollution Problems 2016: The Toxics Beneath Our Feet.* New York and Zurich. https://www.worstpolluted.org/docs/WorldsWorst2016.pdf.

QuintilesIMS Institute (2016). *Outlook for Global Medicines through 2021: Balancing Cost and Value*. https://morningconsult.com/wp-content/uploads/2016/12/QuintilesIMS-Institute-Global-Outlook-FINAL.pdf.

Ramirez-Tejeda, K., Turcotte, D.A. and Pike, S. (2016). Unsustainable wind turbine blade disposal practices in the United States: a case for policy intervention and technological innovation. *New Solutions: A Journal of Environmental and Occupational Health Policy*. 26(4), 581-598. https://doi.org/10.1177/1048291116676098.

Reuters (2018). Agrochemical market share 2018-2023: key findings, regional analysis, top key players updates, future prospects and industry research report, 18 April. https://www.reuters.com/brandfeatures/venture-capital/article?id=33773. Accessed 15 August 2018.

Rim, K.-T. (2017). Reproductive toxic chemicals at work and efforts to protect workers' health: a literature review. *Safety and Health at Work*. 8(2), 143-150. https://doi.org/10.1016/J.SHAW.2017.04.003.

Schulz, O., Rings, T. and Forrest, R. (2012). *Chemical Industry Vision 2030: A European Perspective*. Chicago: A.T.Kearney. https://www.atkearney.ch/chemicals/ideas-insights/article/-/asset_publisher/LCcgOeS4t85g/content/chemical-industry-vision-2030-a-european-perspective/10192?inheritRedirect=false&redirect=https%3A%2F%2Fwww.atkearney.ch%2Fchemicals%2Fideas-insights%2Farticl.

Scott, A. (2017). Pushing wind turbine blades toward 200 meters: Covestro pushes polyurethane, not epoxy, as the polymer needed to make blades bigger and lighter, 24 July. *Chemical & Engineering News*. 20-21. https://cen.acs.org/articles/95/i30/Pushing-wind-turbine-blades-toward.html. Accessed 5 September 2018.

Sharma, V. (2015). *Applicability of Green Chemistry in Pharmaceutical Processes.* Pharma Bio World. https://pdfs.semanticscholar.org/cb38/0ea4d01a006794f90cbfde61be848dbe5882.pdf.

Singhsachakul, N. (2014). The growing promise of ASEAN, 9 June. *Bangkok Post*. https://www.bangkokpost.com/business/news/414384/the-growing-promise-of-asean. Accessed 2 September 2018.

Some of Us (2015). *Bad Medicine: How the Pharmaceuticals Industry is Contributing to the Rise of Antibiotic-Resistant Superbugs*. http://changingmarket.wpengine.com/wp-content/uploads/2016/12/BAD-MEDICINE-Report-FINAL.pdf.

Stanislaus, M. (2017). Electronics: the next frontier in sustainability, 6 January. *The EPA Blog*. https://blog.epa.gov/blog/2017/01/electronics-the-next-frontier-in-sustainability/. Accessed 23 July 2018.

Stanway, D. (2017). China's recyclers eye looming electric vehicle battery mountain, 23 October. *Reuters*. https://www.reuters.com/article/us-china-batteries-recycling-insight/chinas-recyclers-eye-looming-electric-vehicle-battery-mountain-idUSKBN1CR0Y8.

Sustainable Business (2013). Nike moves to water-free, chemical-free dyeing, 17 December. *GreenBiz*. https://www.greenbiz.com/blog/2013/12/17/nike-moves-water-free-chemical-free-dyeing. Accessed 5 September 2018.

Swilling, M., Hajer, M., Baynes, T., Bergesen, J., Labbé, F., Musango, J.K., Ramaswami, A., Robinson, B., Salat, S. and Suh, S. (2018). *The Weight of Cities: Resource Requirements of Future Urbanization*. Nairobi: United Nations Environment Programme. http://www.resourcepanel.org/reports/weight-cities.

Technavio (2018). Global eco fibre market 2018 - 2022. https://www.technavio.com/report/global-eco-fibre-market-analysis-share-2018?utm_source=t6&utm_medium=bw&utm_campaign=businesswire. Accessed 19 July 2018.

Transparency Market Research (2018). Textile chemicals market - global industry analysis, size, share, growth, trends, and forecast 2018 - 2026. https://www.transparencymarketresearch.com/textile-chemicals-market.html. Accessed 5 September 2018.

Tür, M., Manhart, A. and Schleicher, T. (2016). *Generation of Used Lead-Acid Batteries in Africa – Estimating the Volumes*. Berlin: Oko-Institut e.V. http://www.econet.international/fileadmin/user_upload/ULAB_Generation_African_Countries_final_20160411.pdf.

United Nations Department of Economic and Social Affairs (2014a). *World Urbanization Prospects: The 2014 Revision, Highlights*. https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf.

United Nations Department of Economic and Social Affairs (2014b). Cities for a sustainable future, 22 May. http://www.un.org/en/development/desa/news/ecosoc/cities-for-a-sustainable-future.html. Accessed 2 September 2018.

United Nations Department of Economic and Social Affairs (2015). *World Population Ageing 2015*. http://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2015_Report.pdf.

United Nations Department of Economic and Social Affairs (2017). *World Population Prospects: Key Findings and Advance Tables, the 2017 Revision*. https://esa.un.org/unpd/wpp/publications/files/wpp2017_keyfindings.pdf.

United Nations Department of Economic and Social Affairs (2018). *World Urbanization Prospects: The 2018 Revision - Key Facts*. https://esa.un.org/unpd/wup/publications/Files/WUP2018-KeyFacts.pdf.

United Nations Educational Scientific and Cultural Organization Institute for Statistics (n.d.). How much does your country invest in R&D? http://uis.unesco.org/apps/visualisations/research-and-development-spending/. Accessed 31 August 2018.

United Nations Environment Programme (2017). CCAC high level assembly endorses global strategy on low-sulfur fuels and cleaner diesel vehicles, 24 January. https://www.unenvironment.org/news-and-stories/blog-post/ccac-high-level-assembly-endorses-global-strategy-low-sulfur-fuels-and. Accessed 5 September 2018.

United Nations General Assembly (2017). *Fulfilling the Promise of Globalization: Advancing Sustainable Development in an Interconnected World*. https://undocs.org/A/72/301.

United States Environmental Protection Agency (2011). *Steps to Lead Safe Renovation, Repair and Painting.* https://www.epa.gov/sites/production/files/2013-11/documents/steps_0.pdf.

Valencia, R.C. (2013). *The Future of the Chemical Industry by 2050*. Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA. http://doi.wiley.com/10.1002/9783527656998.

van der Kuijp, T.J., Huang, L. and Cherry, C.R. (2013). Health hazards of China's lead-acid battery industry: a review of its market drivers, production processes, and health impacts. *Environmental Health: A Global Access Science Source* 12, 61. https://doi.org/10.1186/1476-069X-12-61.

Whitesides, G.M. (2015). Reinventing chemistry. *Angewandte Chemie* 54(11), 3196-3209. https://doi.org/10.1002/anie.201410884.

World Bank (2018). Transport overview, 19 September. http://www.worldbank.org/en/topic/transport/overview. Accessed 1 January 2019.

World Health Organization (2014). *Chrysotile Asbestos*. http://www.who.int/ipcs/assessment/public_health/chrysotile_asbestos_summary.pdf.

World Intellectual Property Organization (2017). *World Intellectual Property Indicators 2017*. https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2017.pdf.

Zero Discharge of Hazardous Chemicals (2018). About ZDHC. https://www.roadmaptozero.com/about/. Accessed 1 January 2019.

Zimmann, R., O'Brien, H., Hargrave, J. and Morrell, M. (2016). *Circular Economy in the Built Environment*. Blackbourn, M. (ed.). London: Arup. https://www.arup.com/perspectives/publications/research/section/circular-economy-in-the-built-environment.

ZVEI (2017). *The Global Electrical & Electronic Industry – Facts & Figures*. Frankfurt: Zvei Die Elektroindustrie. https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2017/Juli/Die_globale_Elektroindustrie_Daten_Zahlen_Fakten/Fact-Sheet-International-2017.pdf.

## Chapter 4

Accenture (2017). *Taking the European Chemical Industry into the Circular Economy*. https://www.accenture.com/t20170314T154717Z__w__/us-en/_acnmedia/PDF-45/Accenture-CEFIC-Report-Exec-Summary.pdf#zoom=50.

Apparel and Footwear International RSL Management Group (2018). *Chemical Toolkit Version 0.3*. https://www.afirm-group.com/wp-content/uploads/2018/11/FINAL-2018-AFIRM-Toolkit-2018-English.pdf.

Atlas (2018). Where does china export toys nes to? (2017). *The Observatory of Economic Complexity.* https://atlas.media.mit.edu/en/visualize/tree_map/hs92/export/chn/show/950390/2017/. Accessed 6 September 2018.

Baker, J.I. and Hites, R.A. (2000). Is combustion the major source of polychlorinated dibenzo-p-dioxins and dibenzofurans to the environment? a mass balance investigation. *Environmental Science & Technology*. 34(14), 2879-2886. https://doi.org/10.1021/ES9912325.

Bey, N. (2018). Life cycle management. In *Life Cycle Assessment: Theory and Practice*. Hauschild, M. Z., Rosenbaum, R. K., and Olsen, S. I. (eds). Cham: Springer. 519-544. https://doi.org/10.1007/978-3-319-56475-3_22.

Bitran, G.R., Gurumurthi, S. and Sam, S.L. (2006). Emerging trends in supply chain governance. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.882086.

Bodar, C., Spijker, J., Lijzen, J., Waaijers-van der Loop, S., Luit, R., Heugens, E., Janssen, M., Wassenaar, P. and Traas, T. (2018). Risk management of hazardous substances in a circular economy. *Journal of Environmental Management* 212, 108-114. https://doi.org/10.1016/j.jenvman.2018.02.014.

Chua, C.P. (2017). Chemical trade flows: a growth story. *Chemical Market Analysis* 13(4), 8-9. http://www.shipsfocus.com/wp-content/uploads/2018/02/2_Chemical_Market_Outlook-GLOBAL-CHEMICAL-SHIPPING.pdf.

Clark, J.H., Farmer, T.J., Herrero-Davila, L. and Sherwood, J. (2016). Circular economy design considerations for research and process development in the chemical sciences. *Green Chemistry* 18(14), 3914-3934. https://doi.org/10.1039/C6GC00501B.

Compliance and Risks (2018). Global growth of regulations by subject. https://www.complianceandrisks.com/global-growth-regulations-subject/. Accessed 8 September 2018.

European Chemicals Agency (2018a). Inspectors find phthalates in toys and asbestos in second-hand products, 13 February. https://echa.europa.eu/-/inspectors-find-phthalates-in-toys-and-asbestos-in-second-hand-products. Accessed 18 February 2019

European Chemicals Agency (2018b). 82% of inspected internet advertisements for hazardous chemicals lack required warning, 23 April. https://echa.europa.eu/-/82-of-inspected-internet-advertisements-for-hazardous-chemicals-lack-required-warning. Accessed 8 June 2018

European Commission (2018). *Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions - On the Implementation of the Circular Economy Package: Options to Address the Interface between Chemical, Product and Waste Legislation*. Strasbourg: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0032&from=en.

Fantke, P., Ernstoff, A.S., Huang, L., Csiszar, S.A. and Jolliet, O. (2016). Coupled near-field and far-field exposure assessment framework for chemicals in consumer products. *Environment International* 94, 508-518. https://doi.org/10.1016/j.envint.2016.06.010.

Fantke, P., Friedrich, R. and Jolliet, O. (2012). Health impact and damage cost assessment of pesticides in Europe. *Environment International* 49, 9-17. https://doi.org/10.1016/J.ENVINT.2012.08.001.

Fantke, P., Huang, L., Overcash, M., Griffing, E. and Jolliet, O. (2019). Towards a life cycle based chemical alternative assessment (LCAA). *Green Chemistry (Submitted)*.

Fantke, P. and Illner, N. (2019). Goods that are good enough: introducing an absolute sustainability perspective for managing chemicals in consumer products. *Current Opinion in Green and Sustainable Chemistry* 15, 91-97. https://doi.org/10.1016/j.cogsc.2018.12.001.

Global inter-sector standard for Substances in Articles (SiA) communication (2018). *Technical Coordination Meeting: Protocol*. https://sofia-darmstadt.de/fileadmin/Dokumente/Sonstige/LIFEAskREACH/Proactive_Alliance_Meeting_Protocol_2018-06-07_sofia.pdf.

Goldsmith, M.-R., Grulke, C.M., Brooks, R.D., Transue, T.R., Tan, Y.M., Frame, A., Egeghy, P.P., Edwards, R., Chang, D.T., Tornero-Velez, R., Isaacs, K., Wang, A., Johnson, J., Holm, K., Reich, M., Mitchell, J., Vallero, D.A., Phillips, L., Phillips, M., Wambaugh, J.F., Judson, R.S., Buckley, T.J. and Dary, C.C. (2014). Development of a consumer product ingredient database for chemical exposure screening and prioritization. *Food and Chemical Toxicology*. 65, 269-279. https://doi.org/10.1016/J.FCT.2013.12.029.

Grundmann, V., Bilitewski, B., Zehm, A., Darbra, R. and Barceló, D. (2013). Risk-based management of chemicals and products in a circular economy at a global scale- impacts of the FP7 funded project riskcycle. *Environmental Sciences Europe*. 25(1), 14. https://doi.org/10.1186/2190-4715-25-14.

Gutowski, T.G. (2018). A critique of life cycle assessment; where are the people? *Procedia CIRP* 69,11-15. https://doi.org/10.1016/j.procir.2018.01.002.

Hansen, E., Nilsson, N. and Ravnholt Vium, K.S. (2014). *Hazardous Substances in Plastics*. Copenhagen: Danish Environmental Protection Agency. https://www2.mst.dk/Udgiv/publications/2014/12/978-87-93283-31-2.pdf.

Hellweg, S. and Milà i Canals, L. (2014). Emerging approaches, challenges and opportunities in life cycle assessment. *Science*. 344(6188), 1109-1113. https://doi.org/10.1126/science.1248361.

Holt, E., Weber, R., Stevenson, G. and Gaus, C. (2010). Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) impurities in pesticides: a neglected source of contemporary relevance. *Environmental Science & Technology*. 44(14), 5409-5415. https://doi.org/10.1021/es903915k.

Homrich, A.S., Galvão, G., Abadia, L.G. and Carvalho, M.M. (2018). The circular economy umbrella: trends and gaps on integrating pathways. *Journal of Cleaner Production*. 175, 525-543. https://doi.org/10.1016/j.jclepro.2017.11.064.

Ionas, A.C., Dirtu, A.C., Anthonissen, T., Neels, H. and Covaci, A. (2014). Downsides of the recycling process: harmful organic chemicals in children's toys. *Environment International*. 65, 54-62. https://doi.org/10.1016/J.ENVINT.2013.12.019.

Isaacs, K.K., Goldsmith, M.-R., Egeghy, P., Phillips, K., Brooks, R., Hong, T. and Wambaugh, J.F. (2016). Characterization and prediction of chemical functions and weight fractions in consumer products. *Toxicology Reports*. 3, 723-732. https://doi.org/10.1016/J.TOXREP.2016.08.011.

Isaacs, K.K., Phillips, K.A., Biryol, D., Dionisio, K.L. and Price, P.S. (2018). Consumer product chemical weight fractions from ingredient lists. *Journal of Exposure Science and Environmental Epidemiology*. 28(3), 216-222. https://doi.org/10.1038/jes.2017.29.

Jennings, A. (2007). Thomas the tank engine toys recalled because of lead paint. https://www.nytimes.com/2007/06/15/business/15recall.html. Accessed 2 July 2018.

Karami, A., Golieskardi, A., Keong Choo, C., Larat, V., Galloway, T.S. and Salamatinia, B. (2017). The presence of microplastics in commercial salts from different countries. *Scientific Reports*. 7(1), 46173. https://doi.org/10.1038/srep46173.

Kay, J. (2013). Chemicals of high concern found in thousands of children's products. *Environmental Health News*. https://www.scientificamerican.com/article/chemicals-of-high-concern-found-in-thousands-of-childrens-products/. Accessed 28 October 2016.

Kijko, G., Jolliet, O. and Margni, M. (2016). Occupational health impacts due to exposure to organic chemicals over an entire product life cycle. *Environmental Science & Technology*. 50(23), 13105-13114. https://doi.org/10.1021/acs.est.6b04434.

Liao, C. and Kannan, K. (2013). Concentrations and profiles of bisphenol A and other bisphenol analogues in foodstuffs from the United States and their implications for human exposure. *Journal of Agricultural and Food Chemistry*. 61(19), 4655-4662. https://doi.org/10.1021/jf400445n.

Llompart, M., Sanchez-Prado, L., Pablo Lamas, J., Garcia-Jares, C., Roca, E. and Dagnac, T. (2013). Hazardous organic chemicals in rubber recycled tire playgrounds and pavers. *Chemosphere*. 90(2), 423-431. https://doi.org/10.1016/j.chemosphere.2012.07.053.

Martin, M. (2013). *Creating Sustainable Apparel Value Chains: A Primer on Industry Transformation*. 1st edn. Geneva: Impact Economy. www.impacteconomy.com/papers/IE_PRIMER_DECEMBER2013_EN.pdf.

Mitchell, E.A.D., Mulhauser, B., Mulot, M., Mutabazi, A., Glauser, G. and Aebi, A. (2017). A worldwide survey of neonicotinoids in honey. *Science*. 358(6359), 109-111. https://doi.org/10.1126/science.aan3684.

Normile, D. (2017). International trade shifts the burden of pollution-related deaths, 29 March. *Science*. http://doi.org/10.1126/science.aal0979. Accessed 17 February 2019.

O'Rourke, D. (2014). The science of sustainable supply chains. *Science* 344(6188), 1124-1127. https://doi.org/10.1126/science.1248526.

Overcash, M. (2016). Environmental genome of industrial products (EGIP): the missing link for human health. *Green Chemistry*. 18(12), 3600-3606. https://doi.org/10.1039/C6GC00182C.

Phillips, K.A., Wambaugh, J.F., Grulke, C.M., Dionisio, K.L. and Isaacs, K.K. (2017). High-throughput screening of chemicals as functional substitutes using structure-based classification models. *Green Chemistry*. 19(4), 1063-1074. https://doi.org/10.1039/C6GC02744J.

Pieke, E.N., Smedsgaard, J. and Granby, K. (2018). Exploring the chemistry of complex samples by tentative identification and semiquantification: a food contact material case. *Journal of Mass Spectrometry*. 53(4), 323-335. https://doi.org/10.1002/jms.4052.

Pivnenko, K., Olsson, M.E., Götze, R., Eriksson, E. and Astrup, T.F. (2016). Quantification of chemical contaminants in the paper and board fractions of municipal solid waste. *Waste Management*. 51, 43-54. https://doi.org/10.1016/J.WASMAN.2016.03.008.

Samsonek, J. and Puype, F. (2013). Occurrence of brominated flame retardants in black thermo cups and selected kitchen utensils purchased on the European market. *Food Additives & Contaminants: Part A*. 30(11), 1976-1986. https://doi.org/10.1080/19440049.2013.829246.

Schecter, A., Colacino, J., Haffner, D., Patel, K., Opel, M., Päpke, O. and Birnbaum, L. (2010). Perfluorinated compounds, polychlorinated biphenyls, and organochlorine pesticide contamination in composite food samples from Dallas, Texas, USA. *Environmental Health Perspectives*. 118(6), 796-802. https://doi.org/10.1289/ehp.0901347.

Schecter, A., Malik-Bass, N., Calafat, A.M., Kato, K., Colacino, J.A., Gent, T.L., Hynan, L.S., Harris, T.R., Malla, S. and Birnbaum, L. (2011). Polyfluoroalkyl compounds in Texas children from birth through 12 years of age. *Environmental Health Perspectives*. 120(4), 590-594. https://doi.org/10.1289/ehp.1104325.

Sourcemap (2012). *IPhone 5*. [Map]. https://open.sourcemap.com/maps/57d28966df2ac24b524c8ffb. Accessed 19 January 2019.

Skovgaard, M., Encinas, S.R., Jensen, O.C., Andersen, J.H., Condarco, G. and Jørs, E. (2017). Pesticide residues in commercial lettuce, onion, and potato samples from Bolivia – a threat to public health? *Environmental Health Insights*, 11. https://doi.org/10.1177/1178630217704194.

Stringer, L. (2018). Cross-sector group considers blockchain technology for SiA standard, 6 September. *Chemical Watch*. https://chemicalwatch.com/70122/cross-sector-group-considers-blockchain-technology-for-sia-standard?q=martin+führ. Accessed 18 February 2019

Swedish Chemicals Agency (2014). *Analyses by the Swedish Chemicals Agency in Connection with Enforcement 2008-2013*. https://www.kemi.se/global/tillsyns-pm/2014/enforcement-6-14-analyses-2008-2013.pdf.

Swedish Chemicals Agency (2016a). *Chemicals in Products: Challenges and Approaches*. https://www.kemi.se/global/broschyrer/chemicals-in-products.pdf.

Swedish Chemicals Agency (2016b). *Restricted Chemicals Found in Home Electronics*. https://www.kemi.se/en/global/tillsyns-pm/2016/tillsyn-11-16-tillsyn-av-elektriska-lagprisprodukter.pdf.

Turner, A. (2018). Black plastics: linear and circular economies, hazardous additives and marine pollution. Environment International 117, 308-318. https://doi.org/10.1016/j.envint.2018.04.036.

Uding, N. and Schreder, E. (2013). *Chemicals Revealed: Over 5,000 Kids' Products Contain Toxic Chemicals. Seattle: Washington Toxics Coalition*. http://toxicfreefuture.org/wp-content/uploads/2016/09/Chemicals_Revealed_Report.pdf.

United States Government Accountability Office (2017). *Imported Seafood Safety: FDA And USDA Could Strengthen Efforts to Prevent Unsafe Drug Residues*. www.gao.gov/assets/690/687183.pdf.

Villanueva, A. and Eder, P. (2014). *End-of-Waste Criteria for Waste Plastic for Conversion*. Joint Research Centre Technical Reports EUR 26843 EN. Luxembourg: European Commission. https://doi.org/10.1016/J.SCITOTENV.2016.06.118.

Wiedmann, T. and Lenzen, M. (2018). Environmental and social footprints of international trade. *Nature Geoscience*. 11(5), 314-321. https://doi.org/10.1038/s41561-018-0113-9.

World Health Organization (2018). *GEMS/food - home*. https://extranet.who.int/gemsfood/. Accessed 5 June 2018.

## Chapter 5

Annamalai, J. (2015). Occupational health hazards related to informal recycling of E-waste in India: an overview. *Indian Journal of Occupational and Environmental Medicine* 19(1), http://doi.org/10.4103/0019-5278.157013.

Apte, K. and Salvi, S. (2016). Household air pollution and its effects on health. *F1000 Research*. 5. https://doi.org/10.12688/f1000research.7552.1.

Arefin, M.A. and Mallik, A. (2018). Sources and causes of water pollution in Bangladesh: a technical overview. *BIBECHANA* 15(2018), 97-112. https://doi.org/10.3126/bibechana.v15i0.18688.

Awashthi, A.K., Zeng, X. and Li, J. (2016). Environmental pollution of electronic waste recycling in India: a critical review. Environmental Pollution 211, 259-270. https://doi.org/10.1016/j.envpol.2015.11.027.

Babich, M.A., Chen, S.-B., Greene, M.A., Kiss, C.T., Porter, W.K., Smith, T.P., Wind, M.L. and Zamula, W.W. (2004). Risk assessment of oral exposure to diisononyl phthalate from children's products. *Regulatory Toxicology and Pharmacology*. 40(2), 151-167. https://doi.org/10.1016/J.YRTPH.2004.06.005.

Baldé, C.P., Forti V., Gray, V., Kuehr, R. and Stegmann, P. (2017). *The Global E-Waste Monitor 2017*. Bonn, Geneva and Vienna: United Nations University, International Telecommunication Union and the International Solid Waste Association. https://www.itu.int/en/ITU-D/Climate-Change/Pages/Global-E-waste-Monitor-2017.aspx.

Beek, T. aus der, Weber, F.-A., Bergmann, A., Hickmann, S., Ebert, I., Hein, A. and Küster, A. (2016). Pharmaceuticals in the environment – global occurrences and perspectives. *Environmental Toxicology and Chemistry*. 35(4), 823-835. https://doi.org/10.1002/etc.3339.

Benbrook, C.M. (2016). Trends in glyphosate herbicide use in the United States and globally. *Environmental Sciences Europe* 28(1), 1-15. https://doi.org/10.1186/s12302-016-0070-0.

Boucher, J. and Friot, D. (2017). *Primary Microplastics in the Oceans: Global Evaluation of Sources*. Lundin, C. G. and Sousa, J. M. de (eds). Gland: International Union for Conservation of Nature and Natural Resources. https://doi.org/10.2305/iucn.ch.2017.01.en.

Bouma, K. and Schakel, D.J. (2002). Migration of phthalates from PVC toys into saliva simulant by dynamic extraction. *Food Additives and Contaminants* 19(6), 602-610. https://doi.org/10.1080/02652030210125137.

Boxall, A.B.A. (2012). *New and Emerging Water Pollutants Arising from Agriculture*. Paris: Organisation for Economic C ooperation and Development. https://www.oecd.org/tad/sustainable-agriculture/49848768.pdf.

Broughton, E. (2005). The Bhopal disaster and its aftermath: a review. *Environmental Health*. 4(6), 1-6. https://doi.org/10.1186/1476-069X-4-6.

China Labour Bulletin (2018). *China work accident map*. https://maps.clb.org.hk/accidents/en#201801/201807/1821. Accessed 7 September 2018.

China State Administration of Work Safety (2016). *Accident Investigation Report on the Extremely Serious Fire and Explosion at Ruihai International Logistics Hazardous Goods Warehouse at Tianjin Port on 12 August 2015*.

Cogut, A. (2016). *Open Burning of Waste: A Global Health Disaster*. https://regions20.org/wp-content/uploads/2016/08/OPEN-BURNING-OF-WASTE-A-GLOBAL-HEALTH-DISASTER_R20-Research-Paper_Final_29.05.2017.pdf.

Commission for Environmental Cooperation (2016). Summary charts: North America 2013 - top 25 pollutants by total releases and transfers. http://takingstock.cec.org/Charts?ChartType=1&IndustryLevel=3&Measure=3&MediaTypes=29&QueryType=2&ReportType=16&ResultType=1&SummaryType=1&WatershedLevel=2&Years=2013. Accessed 23 May 2018.

Cousins, A.P., Brorström-Lundén, E., Lexén, J. and Rydberg, T. (2018). *Emissions from Articles: Synthesis Report of the ChEmiTecs Research Program*. Stockholm: Swedish Environmental Protection Agency. https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6802-8.pdf?pid=21851.

Csiszar, S.A., Diamond, M.L. and Daggupaty, S.M. (2014). The magnitude and spatial range of current-use urban PCB and PBDE emissions estimated using a coupled multimedia and air transport model. *Environmental Science & Technology* 48(2), 1075-1083. https://doi.org/10.1021/es403080t.

Daniell, W.E., Van Tung, L., Wallace, R.M., Havens, D.J., Karr, C.J., Bich Diep, N., Croteau, G.A., Beaudet, N.J. and Duy Bao, N. (2015). Childhood lead exposure from battery recycling in Vietnam. *BioMed Research International* 2015, 1-10. https://doi.org/10.1155/2015/193715.

de Freytas-Tamura, K. (2018). Plastics pile up as China refuses to take the west's recycling, 11 January. *New York Times*. https://www.nytimes.com/2018/01/11/world/china-recyclables-ban.html.

de Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S. and Rillig, M.C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. *Global Change Biology* 24(4), 1405-1416. https://doi.org/10.1111/gcb.14020.

de Wit, M. de, Hoogzaad, J., Ramkumar, S., Friedl, H. and Douma, A. (2018). *The Circularity Gap Report: An Analysis of the Circular State of the Global Economy*. Amsterdam: Circle Economy. https://docs.wixstatic.com/ugd/ad6e59_733a71635ad946bc9902dbdc52217018.pdf.

Esdaile, L.J. and Chalker, J.M. (2018). The mercury problem in artisanal and small-scale gold mining. *Chemistry - A European Journal*. 24(27), 6905-6916. https://doi.org/10.1002/chem.201704840.

Essel, R., Engel, L., Carus, M. and Heinrich Ahrens, R. (2015). *Sources of Microplastics Relevant to Marine Protection in Germany*. Werner, S. (ed.). Dessau-Roßlau: German Environment Agency. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_64_2015_sources_of_microplastics_relevant_to_marine_protection_1.pdf.

European Commission (2006). *Science for Environment Policy*. http://ec.europa.eu/environment/integration/research/newsalert/pdf/41na1_en.pdf.

European Commission (2014). *Rapex Facts and Figures 2013*. https://ec.europa.eu/consumers/consumers_safety/safety_products/rapex/alerts/repository/content/pages/rapex/reports/docs/rapex_activity_2013_en.pdf.

European Environment Agency (2015). *The European Environment — State and Outlook 2015: Synthesis Report*. https://doi.org/10.2800/944899.

European Environment Agency (2017a). *Air Pollution from Agriculture: Ammonia Exceeds Emission Limits in 2015*. https://www.eea.europa.eu/highlights/air-pollution-from-agriculture-ammonia.

European Environment Agency (2017b). *Air Quality in Europe — 2017 Report*. Copenhagen: European Environment Agency. https://doi.org/10.2800/850018.

European Environment Agency (2018). Persistent organic pollutants, 16 October. https://www.eea.europa.eu/data-and-maps/indicators/eea32-persistent-organic-pollutant-pop-emissions-1/assessment-9. Accessed 6 February 2019.

European Environment Agency (n.d.). European pollutant release and transfer register. https://prtr.eea.europa.eu/#/areaoverview. Accessed 28 October 2016.

Fernandes, G.W., Goulart, F.F., Ranieri, B.D., Coelho, M.S., Dales, K., Boesche, N., Bustamante, M., Carvalho, F.A., Carvalho, D.C., Dirzo, R., Fernandes, S., Galetti, P.M., Millan, V.E.G., Mielke, C., Ramirez, J.L., Neves, A., Rogass, C., Ribeiro, S.P., Scariot, A. and Soares-Filho, B. (2016). Deep into the mud: ecological and socio-economic impacts of the dam breach in Mariana, Brazil. *Natureza & Conservação*. 14(2), 35-45. https://doi.org/10.1016/J.NCON.2016.10.003.

Fernandez-Cornejo, J., Nehring, R., Osteen, C., Wechsler, S., Martin, A. and Vialou, A. (2014). *Pesticide Use in U.S. Agriculture: 21 Selected Crops, 1960-2008*. Washington, D.C.: United States Department of Agriculture. https://www.ers.usda.gov/webdocs/publications/43854/46734_eib124.pdf.

Fiedler, H. (2007). National PCDD/PCDF release inventories under the Stockholm Convention on Persistent Organic Pollutants. *Chemosphere* 67(9), S96-S108. https://doi.org/10.1016/j.chemosphere.2006.05.093.

Geyer, R., Jameck, J.R. and Law, K.L (2017). Production, use, and fate of all plastics ever made. *Science Advances* 3(7), e1700782. http://doi.org/10.1126/sciadv.1700782.

Gibb, H. and O'Leary, K.G. (2014). Mercury exposure and health impacts among individuals in the artisanal and small-scale gold mining community: a comprehensive review. *Environmental Health Perspectives* 122(7), 667-672. https://doi.org/10.1289/ehp.1307864.

Greenwalt, J., Raasakka, N. and Alverson, K. (2018). Building urban resilience to address urbanization and climate change. In *Resilience: The Science of Adaptation to Climate Change*. Zommers, Z. and Alverson, K. D. (eds.). Elsevier Inc. Chapter 12. 151-164. https://doi.org/10.1016/b978-0-12-811891-7.00012-8.

Griggs, T., Lehren, A.W., Popovich, N., Singhvi, A. and Tabuchi, H. (2017). More than 40 sites released hazardous pollutants because of Hurricane Harvey, 9 August. *New York Times*. https://www.nytimes.com/interactive/2017/09/08/us/houston-hurricane-harvey-harzardous-chemicals.html. Accessed 8 June 2018.

Guerreiro, C., Leeuw, F. de, Foltescu, V. and Ortiz, A.G. (2015). *Air Quality in Europe – 2015 Report*. Copenhagen: European Environment Agency. https://www.eea.europa.eu/publications/air-quality-in-europe-2015.

Gyenes, Z. and Wood, M.H. (2014). Lessons learned from major accidents having significant impact on the environment. In *Symposium Series No 159 Hazards 24*. Edinburgh. 1-9. https://doi.org/10.13140/2.1.2897.6005.

He, K., Sun, Z., Hu, Y., Zeng, X., Yu, Z. and Cheng, H. (2017). Comparison of soil heavy metal pollution caused by e-waste recycling activities and traditional industrial operations. Environmental Science and Pollution Research 24(10), 9387-9398. https://doi.org/10.1007/s11356-017-8548-x.

Heacock, M., Kelly, C.B., Asante, K.A., Birnbaum, L.S., Bergman, Å.L., Bruné, M.-N., Buka, I., Carpenter, D.O., Chen, A., Huo, X., Kamel, M., Landrigan, P.J., Magalini, F., Diaz-Barriga, F., Neira, M., Omar, M., Pascale, A., Ruchirawat, M., Sly, L., Sly, P.D., Van den Berg, M. and Suk, W.A. (2016). E-waste and harm to vulnerable populations: a growing global problem. Environmental Health Perspectives 124, 550-555. http://dx.doi.org/10.1289/ehp.1509699.

Hemmatian, B., Abdolhamidzadeh, B., Darbra, R.M. and Casal, J. (2014). The significance of domino effect in chemical accidents. *Journal of Loss Prevention in the Process Industries*. 29, 30-38. https://doi.org/10.1016/J.JLP.2014.01.003.

Hodges, J.E.N., Vamshi, R., Holmes, C., Rowson, M., Miah, T. and Price, O.R. (2014). Combining high-resolution gross domestic product data with home and personal care product market research data to generate a subnational emission inventory for Asia. *Integrated Environmental Assessment and Management* 10(2), 237-246. https://doi.org/10.1002/ieam.1476.

Hoornweg, D. and Bhada-Tata, P. (2012). *What a Waste: A Global Review of Solid Waste Management*. Urban Development Series. Washington, D.C.: World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/17388/68135.pdf?sequence=8&isAllowed=y.

Horney, J.A., Casillas, G.A., Baker, E., Stone, K.W., Kirsch, K.R., Camargo, K., Wade, T.L. and McDonald, T.J. (2018). Comparing residential contamination in a Houston environmental justice neighborhood before and after Hurricane Harvey. *PLOS ONE*. Lau, A. T. Y. (ed.) 13(2), e0192660. https://doi.org/10.1371/journal.pone.0192660.

Huang, L. and Jolliet, O. (2016). A parsimonious model for the release of volatile organic compounds (VOCs) encapsulated in products. *Atmospheric Environment* 127, 223-235. https://doi.org/10.1016/J.ATMOSENV.2015.12.001.

Huang, L., Fantke, P., Ernstoff, A. and Jolliet, O. (2017). A quantitative property-property relationship for the internal diffusion coefficients of organic compounds in solid materials. *Indoor Air* 27(6), 1128-1140. https://doi.org/10.1111/ina.12395.

Hung, H., Katsoyiannis, A.A., Brorström-Lunden, E., Ollafsdottir, K., Aas, W., Breivik, K., Bohlin-Nizzetto, P., Sigurdsson, A., Hakola, H., Bossi, R., Skov, H., Sverko, E., Barresi, E., Fellin, P. and Wilson, S. (2016). Temporal trends of persistent organic pollutants (POPs) in arctic air: 20 years of monitoring under the Arctic Monitoring and Assessment Programme (AMAP). *Environmental Pollution* 217, 52-61. https://doi.org/10.1016/j.envpol.2016.01.079.

Hudson-Edwards, K.A., Jamieson, H.E. and Lottermoser, B.G. (2011). Mine wastes: past, present, future. *Elements* 7(6), 375-380. https://doi.org/10.2113/gselements.7.6.375.

International Energy Agency, International Council of Chemical Associations and Society for Chemical Engineering and Biotechnology (2013). *Technology Roadmap Energy and GHG Reductions in the Chemical Industry via Catalytic Processes*. https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyandGHGReductionsintheChemicalIndustryviaCatalyticProcesses.pdf.

International Solid Waste Association (2015). *Wasted Health: The Tragic Case of Dumpsites*. https://www.iswa.org/fileadmin/galleries/Task_Forces/THE_TRAGIC_CASE_OF_DUMPSITES.pdf.

International Solid Waste Association (2016). *A Roadmap for Closing Waste Dumpsites the World's Most Polluted Places*. Vienna: International Solid Waste Association. https://www.iswa.org/fileadmin/galleries/About%20ISWA/ISWA_Roadmap_Report.pdf.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R. and Law, K.L. (2015). Plastic waste inputs from land into the ocean. *Science* 347(6223), 768-771. https://doi.org/10.1126/science.1260352.

Jeon, S., Kim, K.-T. and Choi, K. (2016). Migration of DEHP and DINP into dust from PVC flooring products at different surface temperature. *Science of The Total Environment* 547, 441-446. https://doi.org/10.1016/j.scitotenv.2015.12.135.

Kaza, Sipa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Washington, D.C.: International Bank for Reconstruction and Development and World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/30317/9781464813290.pdf.

Kratz, S., Schick, J, and Schnug, E. (2016). Trace elements in rock phosphates and P containing mineral and organo-mineral fertilizers sold in Germany. *Science of the Total Environment*, 542B, 1013-1019. https://doi.org/10.1016/j.scitotenv.2015.08.046.

Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H. and Haberl, H. (2017a). Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proceedings of the National Academy of Sciences of the United States* 114(8), 1880-1885. https://doi.org/10.1073/pnas.1613773114.

Krausmann, E., Cruz, A.M. and Salzano, E. and Necci (2017b). *Natech Risk Assessment and Management: Reducing the Risk of Natural-Hazard Impact on Hazardous Installations*. 1st edn. Amsterdam: Elsevier Inc. https://www.elsevier.com/books/natech-risk-assessment-and-management/krausmann/978-0-12-803807-9.

Kumari, K., Kumar, S., Rajagopal, V., Khare, A. and Kumar, R. (2017). Emission from open burning of municipal solid waste in India. *Environmental Technology* 1-14. https://doi.org/10.1080/09593330.2017.1351489.

Larsson, D.G.J. (2014). Pollution from drug manufacturing: review and perspectives. *Philosophical Transactions of the Royal Society B: Biological Sciences* 369(1656), 1-7. https://doi.org/10.1098/rstb.2013.0571.

Larsson, D.G.J., Andremont, A., Bengtsson-Palme, J., Brandt, K.K., de Roda Husman, A.M., Fagerstedt, P., Fick, J., Flach, C.-F., Gaze, W.H., Kuroda, M., Kvint, K., Laxminarayan, R., Manaia, C.M., Nielsen, K.M., Plant, L., Ploy, M.-C., Segovia, C., Simonet, P., Smalla, K., Snape, J., Topp, E., van Hengel, A.J., Verner-Jeffreys, D.W., Virta, M.P.J., Wellington, E.M. and Wernersson, A.-S. (2018). Critical knowledge gaps and research needs related to the environmental dimensions of antibiotic resistance. *Environment International* 117, 132-138. https://doi.org/10.1016/j.envint.2018.04.041.

Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A. and Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature Communications* 8(15611),-1-10. https://doi.org/10.1038/ncomms15611.

Li, L., Zhai, Z., Liu, J. and Hu, J. (2015). Estimating industrial and domestic environmental releases of perfluorooctanoic acid and its salts in China from 2004 to 2012. *Chemosphere* 129, 100-109. https://doi.org/10.1016/j.chemosphere.2014.11.049.

Li, Y., Ping, H., Ma, Z.-H. and Pan, L.-G. (2014). Statistical analysis of sudden chemical leakage accidents reported in China between 2006 and 2011. *Environmental Science and Pollution Research* 21(8), 5547-5553. https://doi.org/10.1007/s11356-013-2279-4.

Liu, Z., Lu, Y., Wang, P., Wang, T., Liu, S., Johnson, A.C., Sweetman, A.J. and Baninla, Y. (2017). Pollution pathways and release estimation of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in central and eastern China. *Science of The Total Environment* 580, 1247-1256. https://doi.org/10.1016/j.scitotenv.2016.12.085.

Luek, J.L. and Gonsior, M. (2017). Organic compounds in hydraulic fracturing fluids and wastewaters: a review. *Water Research* 123, 536-548. https://doi.org/10.1016/J.WATRES.2017.07.012.

Martin, T.E. and Davies, M.P. (2000). *Trends in the Stewardship of Tailings Dams*. Burnaby: AGRA Earth & Environmental Limited. https://pdfs.semanticscholar.org/4a79/1df0b20f9bfdf1b96037b3eb1c2455fb8379.pdf.

Mateo-Sagasta, J., Zadeh, S.M. and Turral, H. (2017). *Water Pollution from Agriculture: A Global Review*. Rome and Colombo: Food and Agriculture Organization of the United Nations and International Water Management Institute on behalf of the Water Land and Ecosystems research program. http://www.fao.org/3/a-i7754e.pdf.

McCarthy, N. (2016). The countries winning the recycling race, 4 March. *Forbes*. https://www.forbes.com/sites/niallmccarthy/2016/03/04/the-countries-winning-the-recycling-race-infographic/#7f0865c2b3da. Accessed 10 July 2018.

McDonald, B.C., de Gouw, J.A., Gilman, J.B., Jathar, S.H., Akherati, A., Cappa, C.D., Jimenez, J.L., Lee-Taylor, J., Hayes, P.L., McKeen, S.A., Cui, Y.Y., Kim, S.-W., Gentner, D.R., Isaacman-VanWertz, G., Goldstein, A.H., Harley, R.A., Frost, G.J., Roberts, J.M., Ryerson, T.B. and Trainer, M. (2018). Volatile chemical products emerging as largest petrochemical source of urban organic emissions. *Science* 359(6377), 760-764. https://doi.org/10.1126/science.aaq0524.

Melymuk, L., Robson, M., Csiszar, S.A., Helm, P.A., Kaltenecker, G., Backus, S., Bradley, L., Gilbert, B., Blanchard, P., Jantunen, L. and Diamond, M.L. (2014). From the city to the lake: loadings of PCBs, PBDEs, PAHs and PCMs from Toronto to lake Ontario. *Environmental Science & Technology* 48(7), 3732-3741. https://doi.org/10.1021/es403209z.

Meng, J., Lu, Y., Wang, T., Wang, P., Giesy, J.P., Sweetman, A.J. and Li, Q. (2017). Life cycle analysis of perfluorooctanoic acid (PFOA) and its salts in China. *Environmental Science and Pollution Research* 24(12), 11254-11264. https://doi.org/10.1007/s11356-017-8678-1.

Michalski, R. and Ficek, A. (2016). Environmental pollution by chemical substances used in the shale gas extraction – a review. *Desalination and Water Treatment*. 57(3), 1336-1343. https://doi.org/10.1080/19443994.2015.1017331.

Molina, M., Zaelke, D., Sarma, K.M., Andersen, S.O., Ramanathan, V. and Kaniaru, D. (2009). Reducing abrupt climate change risk using the montreal protocol and other regulatory actions to complement cuts in CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America* 106(49), 20616-20621. https://doi.org/10.1073/pnas.0902568106.

Montzka, S.A., Dutton, G.S., Yu, P., Ray, E., Portmann, R.W., Daniel, J.S., Kuijpers, L., Hall, B.D., Mondeel, D., Siso, C., Nance, J.D., Rigby, M., Manning, A.J., Hu, L., Moore, F., Miller, B.R. and Elkins, J.W. (2018). An unexpected and persistent increase in global emissions of ozone-depleting CFC-11. *Nature* 557(7705), 413-417. https://doi.org/10.1038/s41586-018-0106-2.

Morrison, G.C., Weschler, C.J. and Bekö, G. (2016). Dermal uptake directly from air under transient conditions: advances in modeling and comparisons with experimental results for human subjects. *Indoor Air* 26(6), 913-924. https://doi.org/10.1111/ina.12277.

Najam, S., NaWaz, R. and Ahmad, S. (2015). Heavy metals contamination of soils and vegetables irrigated with municipal wastewater: a case study of Faisalabad, Pakistan. *Journal of Environmental and Agricultural Sciences* 4, 6-10 . http://www.academia.edu/23376669/Heavy_Metals_Contamination_of_Soils_and_Vegetables_Irrigated_with_.

National Bureau of Statistics of China (2015). *China Statistical Yearbook 2015*. http://www.stats.gov.cn/tjsj/ndsj/2015/indexeh.htm.

National Bureau of Statistics of China (2017). *China Statistical Yearbook 2017*. http://www.stats.gov.cn/tjsj/ndsj/2017/indexeh.htm.

Needhidasan, S., Samuel, M. and Chidambaram, R. (2014). Electronic waste – an emerging threat to the environment of urban India. *Journal of Environmental Health Science & Engineering* 12(36), 1-9. https://doi.org/10.1186/2052-336X-12-36.

Norwegian Institute for Water Research (2018). Microplastics in agricultural soils: a reason to worry? 1 February. https://www.niva.no/en/news/microplastics-in-agricultural-soils-a-reason-to-worry. Accessed 9 September 2018.

Obradović, M., Kalambura, S., Smolec, D. and Jovicić, N. (2014). Dumping and illegal transport of hazardous waste, danger of modern society. *Collegium Antropologicum* 38(2), 793-803. https://www.ncbi.nlm.nih.gov/pubmed/25145025.

Organisation for Economic Co-operation and Development (2018). Introduction to Pollutant Release and Transfer Registers (PRTRs). https://www.oecd.org/env/ehs/pollutant-release-transfer-register/introductionto-pollutant-release-and-transfer-registers.htm. Accessed 7 September 2018.

Owens, B. (2015). Pharmaceuticals in the environment: a growing problem. *The Pharmaceutical Journal*. 294(7850). https://doi.org/10.1211/PJ.2015.20067898.

Phillips McDougal (2018). *Evolution of the Crop Protection Industry since 1960*. Midlothian: Informa. https://agribusinessintelligence.informa.com/~/media/informa-shop-window/agri/images/sample-content/reports/pmd_evolution_of_the_crop_protection_industry.pdf.

Review on Antimicrobial Resistance (2016). *Tackling Drug-Resistant Infections Globally: Final Report and Recommendations*. https://amr-review.org/sites/default/files/160518_Final%20paper_with%20cover.pdf.

Rodríguez Eugenio, N., McLaughlin, M. and Pennock, P. (2018). *Soil Pollution: A Hidden Reality*. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/I9183EN/i9183en.pdf.

Rucevska, I., Nellemann, C., Isarin, N., Yang, W., Liu, N., Yu, K., Sandnæs, S., Olley, K., McCann, H., Devia, L., Bisschop, L., Soesilo, D., Schoolmeester, T., Henriksen, R. and Nilsen, R. (2015). *Waste Crime – Waste Risks Gaps in Meeting the Global Waste Challenge*. Rapid Response Assessment. Nairobi: United Nations Environment Programme. http://web.unep.org/ourplanet/september-2015/unep-publications/waste-crime-waste-risks-gaps-meeting-global-waste-challenge-rapid.

Rydberg, T., Westerdahl, J., Hallberg, E., Öman, A., Andersson, P.L., Haglund, P., Holmgren, T., Fuhrman, F., Molander, S. and Tivander, J. (2011). Emissions of additives from plastics in the societal material stock: a case study for Sweden. In *Global Risk-Based Management of Chemical Additives I: Production, Usage and Environmetal Occurence*. Berlin: Springer. Chapter 14. 253-264. https://doi.org/10.1007/698_2011_107.

Schreinemachers, P. and Tipraqsa, P. (2012). Agricultural pesticides and land use intensification in high, middle and low-income countries. *Food Policy* 37(6), 616-626. https://doi.org/10.1016/J.FOODPOL.2012.06.003.

Secretariat of the Basel, Rotterdam, Sockholm Secretariat (2016). *2014 Hazardous Waste Generation in Selected Countries*. Data provided by e-mail. http://www.brsmeas.org/.

Secretariat of the Stockholm Convention (2017). Outcomes of the effectiveness evaluation of the Stockholm Convention. http://chm.pops.int/Implementation/EffectivenessEvaluation/Outcomes/tabid/5559/Default.aspx. Accessed 11 September 2018.

Secretariat of the Vienna Convention and its Montreal Protocol (2018). Ozone Secretariat: country data. https://ozone.unep.org/countries/data. Accessed 11 September 2018.

Sheldon, R.A. (2017). The e factor 25 years on: the rise of green chemistry and sustainability. *Green Chemistry* 19(1), 18-43. https://doi.org/10.1039/c6gc02157c.

Shukla, S. and Saxena, A. (2018). Global status of nitrate contamination in groundwater: its occurrence, health impacts, and mitigation measures. In *Handbook of Environmental Materials Management*. Cham: Springer. 1-21. https://doi.org/10.1007/978-3-319-58538-3_20-1.

Singer, A.C., Shaw, H., Rhodes, V. and Hart, A. (2016). Review of antimicrobial resistance in the environment and Its relevance to environmental regulators. *Frontiers in Microbiology* 7, 1728. https://doi.org/10.3389/fmicb.2016.01728.

Soldán, P., Pavonič, M. Bouček, J. and Kokeš, J. (2001). Baia Mare accident – brief ecotoxicological report of Czech experts. Ecotoxicology and Environmental Safety 49(3), 255-261. https://doi.org/10.1006/eesa.2001.2070.

Steinemann, A. (2015). Volatile emissions from common consumer products. *Air Quality, Atmosphere & Health* 8(3), 273-281. https://doi.org/10.1007/s11869-015-0327-6.

Streets, D.G., Horowitz, H.M., Jacob, D.J., Lu, Z., Levin, L., ter Schure, A.F.H. and Sunderland, E.M. (2017). Total mercury released to the environment by human activities. *Environmental Science & Technology* 51(11), 5969-5977. https://doi.org/10.1021/acs.est.7b00451.

Sutherland, V.A., Ehrlich, M., Engler, R. and Kulinowski, K. (2018). *Organic Peroxide Decomposition, Release, and Fire at Arkema Crosby Following Hurricane Harvey Flooding Exposures to Emergency Responders, Community Evacuation, and Property Damage Investigation Report*. Washington, D.C.: United States Chemical Safety and Hazard Investigation Board. https://www.csb.gov/assets/1/20/final_arkema_draft_report_2018-05-23.pdf?16272.

Tabuchi, H. and Kaplan, S. (2017). A sea of health and environmental hazards in Houston's floodwaters, 31 August. *New York Times*. https://www.nytimes.com/2017/08/31/us/houston-contaminated-floodwaters.html?mcubz=3. Accessed 8 June 2018.

Texas Commission on Environmental Quality (2017). Reports of air emission events. https://www.tceq.texas.gov/airquality/emission-events/eventreporting. Accessed 7 September 2018.

Topp, E., Larsson, D.G.J., Miller, D.N., Van den Eede, C. and Virta, M.P.J. (2018). Antimicrobial resistance and the environment: assessment of advances, gaps and recommendations for agriculture, aquaculture and pharmaceutical manufacturing. *FEMS Microbiology Ecology* 94(3). https://doi.org/10.1093/femsec/fix185.

Tornero, V. and Hanke, G. (2016). Chemical contaminants entering the marine environment from sea-based sources: a review with a focus on European seas. *Marine Pollution Bulletin* 112(1-2), 17-38. https://doi.org/10.1016/J.MARPOLBUL.2016.06.091.

United Nations Economic and Social Commission for Western Africa (2015). *Review of Innovative and Appropriate Technologies for Waste Management in Morocco and the Arab Region*.. Unpublished data. https://www.unescwa.org/sites/www.unescwa.org/files/events/files/report_innovative-appropriate-technologies-waste-management_arab-region_escwa_2015.pdf.

United Nations Educational Scientific and Cultural Organization (2009). *Water in a Changing World. The United Nations World Water Development Report 3*. https://unesdoc.unesco.org/ark:/48223/pf0000181993.

United Nations Educational Scientific and Cultural Organization (2015). *The United Nations World Water Development Report 2015: Water for a Sustainable World*. http://unesdoc.unesco.org/images/0023/002318/231823E.pdf.

United Nations Educational Scientific and Cultural Organization (2017). *The United Nations World Water Development Report 2017 Facts and Figures: Wastewater the Untapped Resource*. http://unesdoc.unesco.org/images/0024/002475/247553e.pdf.

United Nations Environment Programme (2009). *Task Force Decision XX/7 – Phase 2 Report 'Environmentally Sound Management of Banks Of Ozone-Depleting Substances'*. Technology and Economic Assessment Panel. https://unep.ch/ozone/Assessment_Panels/TEAP/Reports/TEAP_Reports/teap-october-2009-decisionXX-7-task-force-phase2-report.doc.

United Nations Environment Programme (2015). *The Chemicals in Products Programme: Guidance for Stakeholders on Exchanging Chemicals in Products Information*. http://www.saicm.org/Portals/12/Documents/EPI/Guidance%20for%20Stakeholder%20in%20Exchanging%20CiP%20Information_October2015.pdf.

United Nations Environment Programme (2016a). The Kigali Amendment to the Montreal Protocol: another global commitment to stop climate change, 8 December. https://www.unenvironment.org/news-and-stories/news/kigali-amendment-montreal-protocol-another-global-commitment-stop-climate. Accessed 1 January 2019.

United Nations Environment Programme (2016b). *Marine Plastic Debris and Microplastics: Guidelines and Research to Inspire Action and Guide Policy Changes*. http://wedocs.unep.org/handle/20.500.11822/7720.

United Nations Environment Programme and Arctic Monitoring and Assessment Program (2017). *Global Mercury Assessment 2018 – Draft Technical Background Document*. http://wedocs.unep.org/bitstream/handle/20.500.11822/21553/GMACombined.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme and Council for Scientific and Industrial Research (n.d.). *Africa Waste Management Outlook: Summary for Decision-Makers*. https://wedocs.unep.org/bitstream/handle/20.500.11822/25515/Africa_WMO_Summary.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme and GRID Arendal. (2016). *Marine Litter Vital Graphics*. Fabres, J., Savelli, H., Schoolmeester, T., Rucevska, I. and Baker, E. (eds.). United Nations Environment Programme and GRID-Arendal. Nairobi and Arendal. https://wedocs.unep.org/bitstream/handle/20.500.11822/9798/-Marine_litter_Vital_graphics-2016MarineLitterVG.pdf.pdf?isAllowed=y&sequence=3.

United Nations Environment Programme and International Solid Waste Association (2015a). *Global Waste Management Outlook*. Cannon, T. (ed.). Nairobi. https://doi.org/10.18356/765baec0-en.

United Nations Environment Programme and International Solid Waste Association (2015b). *Global Waste Management Outlook: Summary for Decision-Makers*. https://www.iswa.org/fileadmin/galleries/Publications/ISWA_Reports/GWMO_summary_web.pdf.

United Nations Environment Programme and Secretariat of the Stockholm Convention (2017). *Report on the Effectiveness Evaluation of the Stockholm Convention on Persistent Organic Pollutants*. Geneva: Secretariat of the Stockholm Convention. http://chm.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP8/tabid/5309/Default.aspx.

United Nations Statistics Division (2011). Environmental indicators: hazardous waste generation. https://unstats.un.org/unsd/environment/hazardous.htm. Accessed 8 June 2018.

United States Environmental Protection Agency (2016). The hydraulic fracturing water cycle, 16 December. https://www.epa.gov/hfstudy/hydraulic-fracturing-water-cycle. Accessed 7 September 2018.

United States Environmental Protection Agency (2018). Report on the environment. https://cfpub.epa.gov/roe/. Accessed 11 March 2018.

United States Environmental Protection Agency (2019). *2017 Toxics Release Inventory National Analysis*. Washington, D.C. https://www.epa.gov/sites/production/files/2019-02/documents/2017_tri_national_analysis_complete_report.pdf.

United States Environmental Protection Agency (n.d. a). *Enhancing PRTR Comparability to Address Global Sustainability Needs*. Washington, D.C.: George Washington University. https://www.epa.gov/sites/production/files/documents/gwu_global_awareness_report_on_tri.pdf.

United States Environmental Protection Agency (n.d. b). Our nation's air *2017*. https://gispub.epa.gov/air/trendsreport/2017/#introduction. Accessed 14 February 2018.

United States Environmental Protection Agency (n.d. c). EPA's response to Hurricane Harvey. https://epa.maps.arcgis.com/apps/MapJournal/index.html?appid=fadbae6b2832436fb65ca497bd75b9a6. Accessed 7 September 2018.

United States Geological Survey (2016). Contaminants found in groundwater, 2 December. https://water.usgs.gov/edu/groundwater-contaminants.html. Accessed 24 July 2016.

United States House of Representatives (2011). *Chemicals Used in Hydraulic Fracturing*. https://web.archive.org/web/20131004213846/http:/democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic-Fracturing-Chemicals-2011-4-18.pdf.

United States National Oceanic and Atmospheric Administration (2018). What is the biggest source of pollution in the ocean? https://oceanservice.noaa.gov/facts/pollution.html. Accessed 12 September 2016.

van der Wal, M., van der Meulen, M., Tweehuijsen, G., Peterlin, M., Palatinus, A., Kovač Viršek, M., Coscia, L. and Kržan, A. (2015). *Identification and Assessment of Riverine Input of (Marine) Litter. Final Report for the European Commission DG Environment under Framework Contract No ENV.D.2/FRA/2012/0025*. Bristol: Eunomia Research & Consulting. http://mcc.jrc.ec.europa.eu/document.py?code=201606244356.

Varshavsky, J.R., Morello-Frosch, R., Woodruff, T.J. and Zota, A.R. (2018). Dietary sources of cumulative phthalates exposure among the U.S. general population in NHANES 2005–2014. *Environment International*. 115, 417-429. https://doi.org/10.1016/j.envint.2018.02.029.

Wall, B.A., Mateus, A., Marshall, L., Pfeiffer, D.U., Lubroth, J., Ormel, H.J., Otto, P. and Patriarchi, A. (2016). *Drivers, Dynamics and Epidemiology of Antimicrobial Resistance in Animal Production*. Rome: Food and Agriculture Organization of United Nations. http://www.fao.org/3/a-i6209e.pdf.

Wang, B., Fiedler, H., Huang, J., Deng, S., Wang, Y. and Yu, G. (2016). A primary estimate of global PCDD/F release based on the quantity and quality of national economic and social activities. Chemosphere 151, 303-309. https://doi.org/10.1016/j.chemosphere.2016.02.085.

Wang, Y., Cheng, K., Wu, W., Tian, H., Yi, P., Zhi, G., Fan, J. and Liu, S. (2017). Atmospheric emissions of typical toxic heavy metals from open burning of municipal solid waste in China. *Atmospheric Environment*.152, 6-15. https://doi.org/10.1016/J.ATMOSENV.2016.12.017.

Wannaz, C., Franco, A., Kilgallon, J., Hodges, J. and Jolliet, O. (2018). A global framework to model spatial ecosystems exposure to home and personal care chemicals in Asia. *Science of The Total Environment* 622-623, 410-420. https://doi.org/10.1016/j.scitotenv.2017.11.315.

Weber, F.-A., Aus Der Beek, T., Carius, A., Grüttner, G., Hickmann, S., Ebert, I, Hein, A., Küster, A., Rose, J., Koch-Jugl, J. and Stolzenberg, H.-C. (2014). *Pharmaceuticals in the Environment – the Global Perspective: Occurrence, Effects, and Potential Cooperative Action Under SAICM.* Dessau-Roßlau: German Environment Agency. https://www.umweltbundesamt.de/en/publikationen/pharmaceuticals-in-the-environment-the-global.

Wei, G.-L., Li, D.-Q., Zhuo, M.-N., Liao, Y.-S., Xie, Z.-Y., Guo, T.-L., Li, J.-J., Zhang, S.-Y. and Liang, Z.-Q. (2015). Organophosphorus flame retardants and plasticizers: sources, occurrence, toxicity and human exposure. *Environmental Pollution* 196, 29-46. https://doi.org/10.1016/J.ENVPOL.2014.09.012.

Weschler, C.J. and Nazaroff, W.W. (2014). Dermal uptake of organic vapors commonly found in indoor air. *Environmental Science & Technology* 48(2), 1230-1237. https://doi.org/10.1021/es405490a.

Wiedinmyer, C., Yokelson, R.J. and Gullett, B.K. (2014). Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste. *Environmental Science & Technology* 48(16), 9523-9530. https://doi.org/10.1021/es502250z.

Wood, M. (2017). Newsletter-xi - JRC study of chemical accidents in the media during 2016-2017, for OECD, 5 December. European Commission. http://drmkc.jrc.ec.europa.eu/overview/news#news/432/details/8756/newsletter-xi-jrc-study-of-chemical-accidents-in-the-media-during-2016-2017-for-oecd. Accessed 5 June 2018.

World Health Organization (2010). *WHO Guidelines for Indoor Air Quality: Selected Pollutants*. http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf.

World Health Organization (2011). *Mercury in Skin Lightening Products*. http://www.who.int/ipcs/assessment/public_health/mercury_flyer.pdf.

World Health Organization (2014). *WHO Guidelines for Indoor Air Quality: Household Fuel Combustion*. http://www.who.int/airpollution/publications/household-fuel-combustion/en/.

World Health Organization (2017). *Recycling Used Lead-Acid Batteries: Health Considerations*. http://apps.who.int/iris/bitstream/handle/10665/259447/9789241512855-eng.pdf;jsessionid=AD4085391546E7C6FB30CF0DC6401429?sequence=1.

World Health Organization (2018). *Chemical Releases Caused by Natural Hazard Events and Disasters: Information for Public Health Authorities*. https://reliefweb.int/report/world/chemical-releases-caused-natural-hazard-events-and-disasters-information-public-health.

Zalasiewicz, J., Williams, M., Waters, C.N., Barnosky, A.D., Palmesino, J., Rönnskog, A.-S., Edgeworth, M., Neal, C., Cearreta, A., Ellis, E.C., Grinevald, J., Haff, P., Ivar do Sul, J.A., Jeandel, C., Leinfelder, R., McNeill, J.R., Odada, E., Oreskes, N., Price, S.J., Revkin, A., Steffen, W., Summerhayes, C., Vidas, D., Wing, S. and Wolfe, A.P. (2016). Scale and diversity of the physical technosphere: a geological perspective. *The Anthropocene Review* 4(1), 9-22. https://doi.org/10.1177/2053019616677743.

Zhang, G.S. and Liu, Y. F. (2018). The distribution of microplastics in soil aggregate fractions in southwestern China. *Science of the Total Environment* 642, 12-20. https://doi.org/10.1016/j.scitotenv.2018.06.004.

Zhang, M., Buekens, A. and Li, X. (2017). Open burning as a source of dioxins. *Critical Reviews in Environmental Science and Technology* 47(8), 543-620. https://doi.org/10.1080/10643389.2017.1320154.

Zhang, Y., Jacob, D.J., Horowitz, H.M., Chen, L., Amos, H.M., Krabbenhoft, D.P., Slemr, F., St Louis, V.L. and Sunderland, E.M. (2016). Observed decrease in atmospheric mercury explained by global decline in anthropogenic emissions. *Proceedings of the National Academy of Sciences of the United States of America* 113(3), 526-531. https://doi.org/10.1073/pnas.1516312113.

## Chapter 6

Arastoo, H., Hakimovich, A.P. and Esfandiarpour, S. (2015). Assessment of barriers to establish OSH: a country report. *Industrial Health* 53(4), 378-384. https://doi.org/10.2486/indhealth.2013-0234.

Arctic Monitoring and Assessment Programme (2011). *Arctic Pollution 2011*. https://oaarchive.arctic-council.org/handle/11374/634.

Arctic Monitoring and Assessment Programme (2015a). *Summary for Policymakers: Arctic Pollution Issues 2015*. https://www.amap.no/documents/doc/summary-for-policymakers-arctic-pollution-issues-2015/1195.

Arctic Monitoring and Assessment Programme (2015b). *AMAP Assessment 2015: Human Health in the Arctic*. https://www.amap.no/documents/doc/amap-assessment-2015-human-health-in-the-arctic/1346.

Arctic Monitoring and Assessment Programme (2017). *AMAP Assessment 2016: Chemicals of Emerging Arctic Concern*. https://www.amap.no/documents/doc/AMAP-Assessment-2016-Chemicals-of-Emerging-Arctic-Concern/1624.

Arnot, J.A. and Gobas, F.A. (2006). A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environmental Reviews* 14(4), 257-297. https://doi.org/10.1139/a06-005.

Aubail, A., Dietz, R., Rigét, F., Sonne, C., Wiig, Ø. and Caurant, F. (2012). Temporal trend of mercury in polar bears (Ursus Maritimus) from Svalbard using teeth as a biomonitoring tissue. *Journal of Environmental Monitoring* 14(1), 56-63. https://doi.org/10.1039/c1em10681c

Bernhardt, A., Caravanos, J., Fuller, R., Leahy, S. and Pradhan, A. (2019). *Pollution Knows No Borders: How the Pollution Crisis in Low- and Middle-Income Countries Affects Everyone's Health, and What We Can Do to Address It*. New York, NY: Pure Earth. https://www.pureearth.org/wp-content/uploads/2019/01/pe_pollutionknowsnobordersonline.pdf.

Beyer, A., Mackay, D., Matthies, M., Wania, F. and Webster, E. (2000). Assessing long-range transport potential of persistent organic pollutants. *Environmental Science and Technology* 34(4), 699-703. https://doi.org/10.1021/ES990207W.

Bläsing, M. and Amelung, W. (2018). Plastics in soil: Analytical methods and possible sources. *Science of The Total Environment* 612, 422-435. https://doi.org/10.1016/j.scitotenv.2017.08.086.

Boucher, J. and Friot, D. (2017). *Primary Microplastics in the Oceans: Global Evaluation of Sources*. Lundin, C. G. and Sousa, J. M. de (eds.). Gland: International Union for Conservation of Nature and Natural Resources. https://portals.iucn.org/library/sites/library/files/documents/2017-002.pdf.

Braaten, H.F.V., Åkerblom, S., de Wit, H., Skotte, G., Rask, M., Vuorenmaa, J., Kahilainen, K.K., Malinen, T., Rognerud, S., Lydersen, E., Amundsen, P.-A., Kashulin, N., Kashulina, T., Terentyev, P., Christensen, G., Jackson-Blake, L.A., Lund, E. and Rosseland, B.O. (2017). *Spatial and Temporal Trends of Mercury in Freshwater Fish in Fennoscandia (1965-2015)*. Oslo: Norsk institutt for vannforskning. https://brage.bibsys.no/xmlui/handle/11250/2467116.

Byrne, S., Seguinot-Medina, S., Miller, P., Waghiyi, V., Hippel, F.A. von, Buck, C.L. and Carpenter, D.O. (2017). Exposure to polybrominated diphenyl ethers and perfluoroalkyl substances in a remote population of Alaska natives. *Environmental Pollution* 231, 387-395. https://doi.org/10.1016/J.ENVPOL.2017.08.020.

Canadian Council of Ministers and of the Environment (2014). AQMS. https://www.ccme.ca/en/resources/air/aqms.html. Accessed 29 March 2019.

Chakraborty, P., Selvaraj, S., Nakamura, M., Balasubramanian, P., Cincinelli, A. and Bang, J. (2018). PCBs and PCDD/Fs in soil from informal e-waste recycling sites and open dumpsites in India: levels, congener profiles and health risk assessment. *Science of the Total Environment* 621, 930-938. https://www.researchgate.net/publication/321729212_PCBs_and_PCDDFs_in_soil_from_informal_e-waste_recycling_sites_and_open_dumpsites_in_India_Levels_congener_profiles_and_health_risk_assessment.

Chen, D. and Hale, R.C. (2010). A global review of polybrominated diphenyl ether flame retardant contamination in birds. *Environment International* 36(7), 800-811. https://doi.org/10.1016/J.ENVINT.2010.05.013.

Chen, N., Widjajanto, D.W. and Zheng, Y. (2018). Soil problems in China and its lessons for other developing countries. *IOP Conference Series: Earth and Environmental Science* 102(2018), 012001. https://doi.org/10.1088/1755-1315/102/1/012001.

Choi, G.-H., Lee, D.-Y., Jeong, D.-K., Kuppusamy, S., Lee, Y.B., Park, B.-J. and Kim, J.-H. (2017). Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) concentrations in the South Korean agricultural environment: a national survey. *Journal of Integrative Agriculture*. 16(8), 1841-1851. https://doi.org/10.1016/S2095-3119(16)61585-X.

Clune, A.L., Falk, H. and Riederer, A.M. (2011). Mapping global environmental lead poisoning in children. *Journal of Health and Pollution* 1(2), 14-23. https://doi.org/10.5696/2156-9614.1.2.14.

Combi, T., Miserocchi, S., Langone, L. and Guerra, R. (2016). Polychlorinated biphenyls (PCBs) in sediments from the western Adriatic Sea: sources, historical trends and inventories. *Science of The Total Environment* 562, 580-587. https://doi.org/10.1016/J.SCITOTENV.2016.04.086.

Cowell, W.J., Sjödin, A., Jones, R., Wang, Y., Wang, S. and Herbstman, J.B. (2018). Temporal trends and developmental patterns of plasma polybrominated diphenyl ether concentrations over a 15-year period between 1998 and 2013. *Journal of Exposure Science & Environmental Epidemiology* 29(1), 49-60. https://doi.org/10.1038/s41370-018-0031-3.

Dai, H., Jing, S., Wang, H., Ma, Y., Li, L., Song, W. and Kan, H. (2017). VOC characteristics and inhalation health risks in newly renovated residences in Shanghai, China. *Science of The Total Environment* 577, 73-83. https://doi.org/10.1016/J.SCITOTENV.2016.10.071.

Dalahmeh, S., Tirgani, S., Komakech, A.J., Niwagaba, C.B. and Ahrens, L. (2018). Per- and polyfluoroalkyl substances (PFASs) in water, soil and plants in wetlands and agricultural areas in Kampala, Uganda. *Science of the Total Environment* 631-632, 660-667. https://doi.org/10.1016/j.scitotenv.2018.03.024.

Dem, S.B., Cobb, J.M. and Mullins, D.E. (2007). Pesticide residues in soil and water from four cotton growing areas of Mali, West Africa. *Journal of Agriculture, Food and Environmental Science* 1, 1-12. https://www.researchgate.net/publication/284687294_Pesticide_residues_in_soil_and_water_from_four_cotton_growing_areas_of_Mali_West_Africa.

de Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S. and Rillig, M.C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. *Global Change Biology* 24(4), 1405-1416. https://doi.org/10.1111/gcb.14020.

Dewalque, L., Pirard, C. and Charlier, C. (2014). Measurement of urinary biomarkers of parabens, benzophenone-3, and phthalates in a Belgian population. *BioMed Research International* 2014(649314), 1-14. https://doi.org/10.1155/2014/649314.

Dodson, R.E., Udesky, J.O., Colton, M.D., McCauley, M., Camann, D.E., Yau, A.Y., Adamkiewicz, G. and Rudel, R.A. (2017). Chemical exposures in recently renovated low-income housing: influence of building materials and occupant activities. *Environment International* 109, 114-127. https://doi.org/10.1016/J.ENVINT.2017.07.007.

Donnachie, R.L., Johnson, A.C., Moeckel, C., Pereira, M.G. and Sumpter, J.P. (2014). Using risk-ranking of metals to identify which poses the greatest threat to freshwater organisms in the UK. Environmental Pollution 194, 17-23. https://doi.org/10.1016/j.envpol.2014.07.008

Driedger, Alexander G.J., Hans H. Dürr, Kristen Mitchell, Philippe Van Cappellen (2015). Plastic debris in the Laurentian Great Lakes: a review. *Journal of Great Lakes Research*.41(1), 9-19. https://www.sciencedirect.com/science/article/pii/S0380133015000064?via%3Dihub.

Egeghy, P.P., Judson, R., Gangwal, S., Mosher, S., Smith, D., Vail, J. and Cohen Hubal, E.A. (2012). The exposure data landscape for manufactured chemicals. *Science of The Total Environment*. 414, 159-166. https://doi.org/10.1016/j.scitotenv.2011.10.046.

Environment Canada and United States Environmental Protection Agency (2014). *State of the Great Lakes 2011*. https://binational.net/wp-content/uploads/2014/11/sogl-2011-technical-report-en.pdf.

Environmental Working Group (2005). Body burden: the pollution in newborns: detailed findings, 14 July. https://www.ewg.org/research/body-burden-pollution-newborns/detailed-findings. Accessed 15 February 2019.

Environmental Working Group (2009). Pollution in minority newborns, 23 November. https://www.ewg.org/research/minority-cord-blood-report. Accessed 15 February 2019.

Environmental Working Group (2019). EWG's 2019 shopper's guide to pesticides in produceTM: over half of samples of kale tainted with possible cancer-causing chemical, 20 March. https://www.ewg.org/foodnews/summary.php. Accessed 28 March 2019.

Eriksen, M., Mason, S., Wilson, S., Box, C., Zellers, A., Edwards, W., Farley, H. and Amato, S. (2013). Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Marine Pollution Bulletin* 77, 177-182. https://doi.org/10.1016/j.marpolbul.2013.10.007.

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., and Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PloS One* 9, e111913. https://doi.org/10.1371/journal.pone.0111913.

Eriksson, U., Mueller, J.F., Toms, L.-M.L., Hobson, P. and Kärrman, A. (2017). Temporal trends of PFSAs, PFCAs and selected precursors in Australian serum from 2002 to 2013. *Environmental Pollution* 220, 168-177. https://doi.org/10.1016/J.ENVPOL.2016.09.036.

Eurekalert (2018). Microplastics discovered in human stools across the globe in 'first study of its kind', 22 October. https://www.eurekalert.org/pub_releases/2018-10/sh-mdi101518.php.

European Environment Agency (2015). Air pollution, 18 February. https://www.eea.europa.eu/soer-2015/europe/air. Accessed 4 June 2018.

European Environment Agency (2016). Indoor air quality, 3 June. https://www.eea.europa.eu/signals/signals-2013/articles/indoor-air-quality.

European Food Safety Authority (2018). The 2016 European Union report on pesticide residues in food. *EFSA Journal* 16(7), 5348. https://doi.org/10.2903/j.efsa.2018.5348.

Evans, M., Muir, D., Brua, R.B., Keating, J. and Wang, X. (2013). Mercury trends in predatory fish in Great Slave Lake: the influence of temperature and other climate drivers. *Environmental Science & Technology* 47(22), 12793-12801. https://doi.org/10.1021/es402645x.

Fantke, P., Ernstoff, A.S., Huang, L., Csiszar, S.A. and Jolliet, O. (2016). Coupled near-field and far-field exposure assessment framework for chemicals in consumer products. *Environment International* 94, 508-518. https://doi.org/10.1016/j.envint.2016.06.010.

Ferguson, K.K., Colacino, J.A., Lewis, R.C. and Meeker, J.D. (2017). Personal care product use among adults in NHANES: associations between urinary phthalate metabolites and phenols and use of mouthwash and sunscreen. *Journal of Exposure Science & Environmental Epidemiology* 27(3), 326-332. https://doi.org/10.1038/jes.2016.27.

Ferrario, C., Finizio, A., Villa, S. (2017). Legacy and emerging contaminants in meltwater of three Alpine glaciers. *Science of the Total Environemnt*. 574, 350-357. https://doi.org/10.1016/j.scitotenv.2016.09.067.

Filella, M. and Turner, A. (2018). Observational Study Unveils the Extensive Presence of Hazardous Elements in Beached Plastics from Lake Geneva. *Frontiers in Environmental Science,* 6, 1-8. https://doi.org/10.3389/fenvs.2018.00001.

Fisher, M., Arbuckle, T.E., Liang, C.L., LeBlanc, A., Gaudreau, E., Foster, W.G., Haines, D., Davis, K. and Fraser, W.D. (2016). Concentrations of persistent organic pollutants in maternal and cord blood from the maternal-infant research on environmental chemicals (MIREC) cohort study. *Environmental Health* 15(59), 1-14. https://doi.org/10.1186/s12940-016-0143-y.

Fisher, M., MacPherson, S., Braun, J.M., Hauser, R., Walker, M., Feeley, M., Mallick, R., Bérubé, R. and Arbuckle, T.E. (2017). Paraben concentrations in maternal urine and breast milk and its association with personal care product use. *Environmental Science & Technology* 51(7), 4009-4017. https://doi.org/10.1021/acs.est.6b04302.

Gandhi, N., Gewurtz, S.B., Drouillard, K.G., Kolic, T., MacPherson, K., Reiner, E.J. and Bhavsar, S.P. (2017). Polybrominated diphenyl ethers (PBDEs) in Great Lakes fish: levels, patterns, trends and implications for human exposure. *Science of The Total Environment* 576, 907-916. https://doi.org/10.1016/J.SCITOTENV.2016.10.043.

German Environment Agency (n.d.). Database - pharmaceuticals in the environment. https://www.umweltbundesamt.de/en/database-pharmaceuticals-in-the-environment-0. Accessed 29 March 2019.

Guo, Y., Wang, L. and Kannan, K. (2014). Phthalates and parabens in personal care products from China: concentrations and human exposure. *Archives of Environmental Contamination and Toxicology* 66(1), 113-119. https://doi.org/10.1007/s00244-013-9937-x.

Gyllenhammar, I., Glynn, A., Jönsson, B.A.G., Lindh, C.H., Darnerud, O., Svensson, K. and Lignell, S. (2016). Diverging temporal trends of human exposure to bisphenols and plastizisers, such as phthalates, caused by substitution of legacy EDCs?. *Environmental Research* 153, 48-54. https://doi.org/10.1016/j.envres.2016.11.012.

Hartmann N.B. (2018). Focusing on microplastic in honey or beer masks a bigger problem, 12 May. *ScienceNordic*. http://sciencenordic.com/focusing-microplastic-honey-or-beer-masks-much-bigger-problem. Accessed 15 February 2019.

Ho, K.K.Y., Zhou, G.-J., Xu, E.G.B., Wang, X. and Leung, K.M.Y. (2016). Long-term spatio-temporal trends of organotin contaminations in the marine environment of Hong Kong. *PLoS ONE*. Khim, J.S. (ed.) 11(5), 1-17. https://doi.org/10.1371/journal.pone.0155632.

Hoffman, K., Butt, C.M., Webster, T.F., Preston, E. V., Hammel, S.C., Makey, C., Lorenzo, A.M., Cooper, E.M., Carignan, C., Meeker, J.D., Hauser, R., Soubry, A., Murphy, S.K., Price, T.M., Hoyo, C., Mendelsohn, E., Congleton, J., Daniels, J.L. and Stapleton, H.M. (2017). Temporal trends in exposure to organophosphate flame retardants in the United States. *Environmental Science & Technology Letters*. 4(3), 112-118. https://doi.org/10.1021/acs.estlett.6b00475.

Huang, L., Ernstoff, A., Fantke, P., Csiszar, S.A. and Jolliet, O. (2017). A review of models for near-field exposure pathways of chemicals in consumer products. *Science of The Total Environment*. 574, 1182-1208. https://doi.org/10.1016/J.SCITOTENV.2016.06.118.

Huang, R., Liu, Z., Yin, H., Dang, Z., Wu, P., Zhu, N. and Lin, Z. (2018). Bisphenol A concentrations in human urine, human intakes across six continents, and annual trends of average intakes in adult and child populations worldwide: a thorough literature review. *Science of The Total Environment*. 626, 971-981. https://doi.org/10.1016/J.SCITOTENV.2018.01.144.

Hughes, S.R., Kay, P. and Brown, L.E. (2013). Global synthesis and critical evaluation of pharmaceutical data sets collected from river systems. *Environmental Science & Technology* 47(2), 661-677. https://doi.org/10.1021/es3030148.

Human Biomonitoring for Europe (2018). The HBM4EU. https://www.hbm4eu.eu/about-hbm4eu/. Accessed 30 December 2018.

Hunt, P.A., Sathyanarayana, S., Fowler, P.A. and Trasande, L. (2016). Female reproductive disorders, diseases, and costs of exposure to endocrine disrupting chemicals in the European Union. *Journal of Clinical Endocrinology & Metabolism* 101(4), 1562-1570. https://doi.org/10.1210/jc.2015-2873.

Hurley, S., Goldberg, D., Wang, M., Park, J.-S., Petreas, M., Bernstein, L., Anton-Culver, H., Nelson, D.O. and Reynolds, P. (2018). Time trends in per- and polyfluoroalkyl substances (PFASs) in California women: declining serum levels, 2011–2015. *Environmental Science & Technology* 52(1), 277-287. https://doi.org/10.1021/acs.est.7b04650.

Isaacs, K.K., Glen, W.G., Egeghy, P., Goldsmith, M.-R., Smith, L., Vallero, D., Brooks, R., Grulke, C.M. and Özkaynak, H. (2014). SHEDS-HT: an integrated probabilistic exposure model for prioritizing exposures to chemicals with near-field and dietary sources. *Environmental Science & Technology* 48(21), 12750-12759. https://doi.org/10.1021/es502513w.

Jamieson, A.J., Malkocs, T., Piertney, S.B., Fujii, T. and Zhang, Z. (2017). Bioaccumulation of persistent organic pollutants in the deepest ocean fauna. *Nature Ecology & Evolution* 1(0051), 1-4. https://doi.org/10.1038/s41559-016-0051.

Kijko, G., Margni, M., Partovi-Nia, V., Doudrich, G. and Jolliet, O. (2015). Impact of occupational exposure to organic chemicals in life cycle assessment: a new framework based on measured concentrations and labor hours. *Environmental Science & Technology* 49(14), 8741-8750. https://doi.org/10.1021/acs.est.5b00078.

Kim, J.-W., Isobe, T., Muto, M., Tue, N.M., Katsura, K., Malarvannan, G., Sudaryanto, A., Chang, K.-H., Prudente, M., Viet, P.H., Takahashi, S. and Tanabe, S. (2014). Organophosphorus flame retardants (PFRs) in human breast milk from several asian countries. *Chemosphere* 116, 91-97. https://doi.org/10.1016/J.CHEMOSPHERE.2014.02.033.

Kim, S.-K. and Yoon, J. (2014). Chronological trends of emission, environmental level and human exposure of POPs over the last 10 years (1999-2010) in Korea: implication to science and policy. *Science of The Total Environment* 470-471, 1346-1361. https://doi.org/10.1016/J.SCITOTENV.2013.07.031.

Kosuth, M., Mason, S.A. and Wattenberg, E.V. (2018). Anthropogenic contamination of tap water, beer, and sea salt. *PLoS ONE* 3(4) 1-18. https://doi.org/10.1371/journal.pone.0194970.

Kristensen, L.J., Taylor, M.P. and Flegal, A.R. (2017). An odyssey of environmental pollution: the rise, fall and remobilisation of industrial lead in Australia. *Applied Geochemistry* 83, 3-13. https://doi.org/10.1016/j.apgeochem.2017.02.007.

Kumar, A. and Scott Clark, C. (2009). Lead loadings in household dust in Delhi, India. *Indoor Air* 19(5), 414-420. https://doi.org/10.1111/j.1600-0668.2009.00605.x.

Kunacheva, C., Fujii, S., Tanaka, S., Seneviratne, S.T., Lien, N.P.H., Nozoe, M., Kimura, K., Shivakoti, B.R. and Harada, H. (2012). Worldwide surveys of perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) in water environment in recent years. *Water Science & Technology* 66(12), 2764-2771. https://doi.org/10.2166/wst.2012.518.

Lang, C., Fisher, M., Neisa, A., MacKinnon, L., Kuchta, S., MacPherson, S., Probert, A. and Arbuckle, T.E. (2016). Personal care product use in pregnancy and the postpartum period: implications for exposure assessment. *International Journal of Environmental Research and Public Health* 13(106), 1-20. https://doi.org/10.3390/ijerph13010105.

Lapworth, D. J., Baran, N., Stuart, M. E., Ward, R. S. (2012). Emerging contaminants in groundwater: A review of souirces, fate and occurrence. *Environmental Pollution* 163, 287-303. https://doi.org/10.1016/j.envpol.2011.12.034.

Law, R.J., Covaci, A., Harrad, S., Herzke, D., Abdallah, M.A.-E., Fernie, K., Toms, L.-M.L. and Takigami, H. (2014). Levels and trends of PBDEs and HBCDs in the global environment: status at the end of 2012. *Environment International* 65, 147-158. https://doi.org/10.1016/j.envint.2014.01.006.

Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A. and Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature Communications* 8(15611), 1-10. https://doi.org/10.1038/ncomms15611.

Leung, A.O.W., Luksemburg, W.J., Wong, A.S. and Wong, M.H. (2007). Spatial distribution of polybrominated diphenyl ethers and polychlorinated dibenzo-p-dioxins and dibenzofurans in soil and combusted residue at Guiyu, an electronic waste recycling site in Southeast China. *Environmental Science and Technology* 41(8), 2730-2737. https://pubs.acs.org/doi/pdf/10.1021/es0625935.

Li, F., Zhang, C., Qu, Y., Chen, J., Chen, L., Liu, Y. and Zhou, Q. (2010). Quantitative characterization of short- and long-chain perfluorinated acids in solid matrices in Shanghai, China. *Science of the Total Environment* 408, 617-623. https://doi.org/10.1016/j.scitotenv.2009.10.032.

Li, J., Yuan, G.L., Wu, M.Z., Sun, Y., Han, P. and Wang, G.H. (2017a). Evidence for persistent organic pollutants released from melting glacier in the central Tibetan Plateau, China. *Environmental Pollution* 220, Part A, 178-185. https://doi.org/10.1016/j.envpol.2016.09.037.

Li, T., Zhang, S., Tan, Z. and Dai, Y. (2017b). Trend of childhood blood lead levels in cities of China in recent 10 years. *Environmental Science and Pollution Research*. 24, 5824-5830. https://doi.org/10.1007/s11356-016-8335-0.

Li, P., Jin, J., Wang, Y., Hu, J., Xu, M., Sun, Y. and Ma, Y. (2017c). Concentrations of organophosphorus, polybromobenzene, and polybrominated diphenyl ether flame retardants in human serum, and relationships between concentrations and donor ages. *Chemosphere* 171, 654-660. https://doi.org/10.1016/J.CHEMOSPHERE.2016.12.126.

Liao, C. and Kannan, K. (2013). Concentrations and profiles of bisphenol A and other bisphenol analogues in foodstuffs from the United States and their implications for human exposure. *Journal of Agricultural and Food Chemistry* 61(19), 4655-4662. https://doi.org/10.1021/jf400445n.

Liao, C. and Kannan, K. (2018). Temporal trends of parabens and their metabolites in mollusks from the Chinese Bohai Sea during 2006-2015: species-specific accumulation and implications for human exposure. *Environmental Science & Technology* 52(16), 9045-9055. https://doi.org/10.1021/acs.est.8b02750.

Lucattini, L., Poma, G., Covaci, A., de Boer, J., Lamoree, M.H. and Leonards, P.E.G. (2018). A review of semi-volatile organic compounds (SVOCs) in the indoor environment: occurrence in consumer products, indoor air and dust. *Chemosphere* 201, 466-482. https://doi.org/10.1016/j.chemosphere.2018.02.161.

MacLeod, M., von Waldow, H., Tay, P., Armitage, J.M., Wöhrnschimmel, H., Riley, W.J., McKone, T.E. and Hungerbuhler, K. (2011). BETR global – a geographically-explicit global-scale multimedia contaminant fate model. *Environmental Pollution* 159(5), 1442-1445. https://doi.org/10.1016/J.ENVPOL.2011.01.038.

Malaj, E., von der Ohe, P.C., Grote, M., Kühne, R., Mondy, C.P., Usseglio-Polatera, P., Brack, W. and Schäfer, R.B. (2014). Organic chemicals jeopardize the health of freshwater ecosystems on the continental scale. *Proceedings of the National Academy of Sciences of the United States of America* 111(26), 9549-9554. https://doi.org/10.1073/pnas.1321082111.

Mason, S.A., Welch, V. and Nertko, J. (2018). *Synthetic Polymer Contamination in Bottled Water*. State University of New York at Fredonia, Department of Geology and Environmental Sciences. https://orbmedia.org/sites/default/files/FinalBottledWaterReport.pdf.

McGoldrick, D.J. and Murphy, E.W. (2016). Concentration and distribution of contaminants in lake trout and walleye from the Laurentian Great Lakes (2008-2012). *Environmental Pollution* 217, 85-96. https://doi.org/10.1016/j.envpol.2015.12.019.

McGrath, T.J., Ball, A.S. and Clarke, B.O. (2017). Critical review of soil contamination by polybrominated diphenyl ethers (PBDEs) and novel brominated flame retardants (NBFRs); concentrations, sources and congener profiles. *Environmental Pollution* 230, 741-757. https://doi.org/10.1016/J.ENVPOL.2017.07.009.

McNeill, F.E., Fisher, M., Chettle, D.R., Inskip, M., Healey, N., Bray, R., Webber, C.E., Manton, W.I., Marro, L. and Arbuckle, T.E. (2017). The decrease in population bone lead levels in Canada between 1993 and 2010 as assessed by *in vivo* XRF. *Physiological Measurement* 39(015005), 1-16. https://doi.org/10.1088/1361-6579/aa904f.

Mendonca, K., Hauser, R., Calafat, A.M., Arbuckle, T.E. and Duty, S.M. (2014). Bisphenol A concentrations in maternal breast milk and infant urine. *International Archives of Occupational and Environmental Health* 87(1), 13-20. https://doi.org/10.1007/s00420-012-0834-9.

Mercier, F., Glorennec, P., Thomas, O. and Bot, B. Le (2011). Organic contamination of settled house dust, a review for exposure assessment purposes. *Environmental Science & Technology* 45(16), 6716-6727. https://doi.org/10.1021/es200925h.

Meyer, J., Jaspers, V.L.B., Eens, M. and Coen, W. de (2009). The relationship between perfluorinated chemical levels in the feathers and livers of birds from different trophic levels. *Science of the Total Environment* 407, 5894-5900. https://doi.org/10.1016/j.scitotenv.2009.07.032.

Miranda, D. and Carvalho-Souza, G.F. (2016). Are we eating plastic-ingesting fish? *Marine Pollution Bulletin* 103(1-2), 109-114. https://doi.org/10.1016/j.marpolbul.2015.12.035.

Mitchell, E.A.D., Mulhauser, B., Mulot, M., Mutabazi, A., Glauser, G. and Aebi, A. (2017). A worldwide survey of neonicotinoids in honey. *Science* 358(6359), 109-111. https://doi.org/10.1126/science.aan3684.

Mitro, S.D., Dodson, R.E., Singla, V., Adamkiewicz, G., Elmi, A.F., Tilly, M.K. and Zota, A.R. (2016). Consumer product chemicals in indoor dust: a quantitative meta-analysis of U.S. studies. *Environmental Science & Technology* 50(19), 10661-10672. https://doi.org/10.1021/acs.est.6b02023.

Moore, C.J., Moore, S.L., Leecaster, M.K. and Weisberg, S.B., (2001). A comparison of plastic and plankton in the North Pacific Central Gyre. *Marine Pollution Bulletin* 42, 1297-1300. ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/AnnualReports/1999AnnualReport/10_ar11.pdf.

Moore, C., Lattin, G. and Zellers, A. (2011). Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. *Journal of Integrated Coastal Zone Management* 11, 65-73. http://doi.org/10.5894/rgci194.

Morgan, Marsha K. (2012). Children's exposures to Pyrethroid insecticides at home: a review of data collected in published exposure measurement studies conducted in the United States. *International Journal of Environmental Research and Public Health* 9(8), 2964-2985. https://doi.org/10.3390/ijerph9082964.

Nagai, N., Arataki, H., Aoyama, T., Raj, S. and Cai, Z. (2015). *The 2nd POPs Monitoring Report, Asia-Pacific Region: Global Monitoring Plan Under the Stockholm Convention*. Geneva: Secretariat of the Stockholm Convention. http://chm.pops.int/Implementation/GlobalMonitoringPlan/MonitoringReports/tabid/525/Default.aspx.

Naik, A. (2018). *Difference between bioaccumulation and biomagnification*. [Illustration]. Buzzle. https://sciencestruck.com/difference-between-bioaccumulation-biomagnification. Accessed 16 October 2018.

Nøst, T.H., Vestergren, R., Berg, V., Nieboer, E., Odland, J.Ø. and Sandanger, T.M. (2014). Repeated measurements of per- and polyfluoroalkyl substances (PFASs) from 1979 to 2007 in males from northern Norway: assessing time trends, compound correlations and relations to age/birth cohort. *Environment International* 67, 43-53. https://doi.org/10.1016/J.ENVINT.2014.02.011.

Ogundele, D.T., Adio, A.A. and Oludele, O.E. (2015). Heavy metal concentrations in plants and soil along heavy traffic roads in North Central Nigeria. *Journal of Environmental & Analytical Toxicology* 5(06), 1-5. https://doi.org/10.4172/2161-0525.1000334.

Park, J.-S., Voss, R.W., McNeel, S., Wu, N., Guo, T., Wang, Y., Israel, L., Das, R. and Petreas, M. (2015). High exposure of California firefighters to polybrominated diphenyl ethers. *Environmental Science & Technology* 49(5), 2948-2958. https://doi.org/10.1021/es5055918.

Parker, L. (2018). In a first, microplastics found in human poop, 22 October. *National Geographic*. https://www.nationalgeographic.com/environment/2018/10/news-plastics-microplastics-human-feces/. Accessed 15 February 2019.

Quintili, R. (2018). In Italy the first analysis carried out by *Il Salvagente* find microplastics in industrial soft drink, 26 September. *Il Salvagente*. https://ilsalvagente.it/2018/09/26/in-italy-the-first-analysis-carried-out-by-il-salvagente-find-microplastics-in-industrial-soft-drink/. Accessed 15 February 2019.

Rasmussen, P.E., Beauchemin, S., Chénier, M., Levesque, C., MacLean, L.C.W., Marro, L., Jones-Otazo, H., Petrovic, S., McDonald, L.T. and Gardner, H.D. (2011) Canadian House Dust Study: Lead Bioaccessibility and Speciation. *Environmental Science & Technology 45*(11), 4959-4965. https://doi.org/10.1021/es104056m.

Rauert, C., Schuster, J.K., Eng, A. and Harner, T. (2018). Global atmospheric concentrations of brominated and chlorinated flame retardants and organophosphate esters. *Environmental Science & Technology* 52(5), 2777-2789. https://doi.org/10.1021/acs.est.7b06239.

Riddell, T.J., Solon, O., Quimbo, S.A., Tan, C.M.C., Butrick, E. and Peabody, J.W. (2007). Elevated blood-lead levels among children living in the rural Philippines. *Bulletin of the World Health Organization* 85(9), 674-680. https://doi.org/10.2471/BLT.06.036137.

Rios, L.M., Moore, C. and Jones, P.R. (2007). Persistent organic pollutants carried by synthetic polymers in the ocean environment. *Marine Pollution Bulletin* 54(8), 1230-1237. https://doi.org/10.1016/J.MARPOLBUL.2007.03.022.

Rochman, C. M., Tahir, A., Williams, S. L. Baxa, D. V. Lam, R. Miler, J. T., The, F. C., Weroliangi, S., The, S.J. (2015). Anthropogenic debris in seafood: Plastic debris and fibres from textiles in fish and bivalves sold for human consumption. *Nature Scientific Reports*. 5(14340), 1-10. https://doi.org/10.1038/srep14340.

Rothenberg, E., Jackson, B.P., McCalla, G.C., Donohue, A. and Emmons, A.M. (2017). Co-exposure to methylmercury and inorganic arsenic in baby rice cereals and rice-containing teething biscuits. *Environmental Research* 159, 639-647. https://doi.org/10.1016/j.envres.2017.08.046.

Rummel, C. D., Löder, M. G J., Fricke, N., Lang, T. Griebeler, E. M., Janke, M., Gerdts, G. (2016). Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. *Marine Pollution Bulletin* 102(1), 134-141. https://doi.org/10.1016/j.marpolbul.2015.11.043

Scheuhammer, A., Braune, B., Chan, H.M., Frouin, H., Krey, A., Letcher, R., Loseto, L., Noël, M., Ostertag, S., Ross, P. and Wayland, M. (2015). Recent progress on our understanding of the biological effects of mercury in fish and wildlife in the Canadian Arctic. *Science of the Total Environment* 509-510, 91-103. https://doi.org/10.1016/j.scitotenv.2014.05.142.

Scheurer, M. and Bigalke, M. (2018). Microplastics in Swiss floodplain soils. *Environmental Science and Technology* 52(6), 3591-3598. http://doi.org/10.1021/acs.est.7b06003.

Schoeters, G., Govarts, E., Bruckers, L., Hond, E. Den, Nelen, V., Henauw, S. de, Sioen, I., Nawrot, T.S., Plusquin, M., Vriens, A., Covaci, A., Loots, I., Morrens, B., Coertjens, D., Larebeke, N. Van, Craemer, S. de, Croes, K., Lambrechts, N., Colles, A. and Baeyens, W. (2017). Three cycles of human biomonitoring in flanders − time trends observed in the flemish environment and health study. *International Journal of Hygiene and Environmental Health* 220(2), 36-45. https://doi.org/10.1016/J.IJHEH.2016.11.006.

Schröter-Kermani, C., Müller, J., Jürling, H., Conrad, A. and Schulte, C. (2013). Retrospective monitoring of perfluorocarboxylates and perfluorosulfonates in human plasma archived by the German Environmental Specimen Bank. *International Journal of Hygiene and Environmental Heath* 216(6), 633-640. https://doi.org/10.1016/j.ijheh.2012.08.004.

Schuster, P.F., Schaefer, K.M., Aiken, G.R., Antweiler, R.C., Dewild, J.F., Gryziec, J.D, Gusmeroli, A., Hugelius, G., Jafarov, E., Krabbenhoft, D.P., Liu, L., Herman-Mercer, N., Mu, C., Roth, D.A., Schaefer, T., Striegl, R.G., Wickland, K.P. and Zhang, T. (2018). Permafrost stores a globally significant amount of mercury. *Geophysical Research Letters* 45, 1463-1471. https://doi.org/10.1002/2017GL075571.

Schwab, P., Liebmann, B., Köppel, S. and Reiberger, T. (2018). *Assessment of Microplastic Concentrations in Human Stool - Preliminary Results of a Prospective Study*. Presented at United European Gastroenterology (UEG) Week 2018, Vienna, Austria, 24 October 2018. http://www.umweltbundesamt.at/fileadmin/site/presse/news_2018/UEG_Week_2018_-_Philipp_Schwabl_Microplastics_Web.pdf.

Šebková, K., Borůvková, J., Přibylová, P., Vrana, B., Hůlek, R., Holoubek, I. *and Klánová, J.* (2014). *Global Monitoring Plan for Persistent Organic Pollutants Under the Stockholm Convention Article 16 on Effectiveness Evaluation: Second Regional Monitoring Report of the Central, Eastern European and Central Asian Region*. Brno: Research Centre for Toxic Compounds in the Environment, Masaryk University. http://chm.pops.int/Implementation/GlobalMonitoringPlan/MonitoringReports/tabid/525/Default.aspx.

Sebille, E. van, Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Franeker, J.A. van, Eriksen, M., Siegel, D., Galgani, F. and Law, K.L. (2015). A global inventory of small floating plastic debris. *Environmental Research Letters* 10(12), 1-11. https://doi.org/10.1088/1748-9326/10/12/124006.

Secretariat of the Strategic Approach to International Chemicals Management (2018). *Gender and the Sound Management of Chemicals and Waste: Prepared for the Intersessional Process Considering the Strategic Approach and the Sound Management of Chemicals and Waste beyond 2020*. http://www.un.org/womenwatch/osagi/conceptsandefinitions.htm.

Seltenrich, N. (2015). New link in the food chain? Marine plastic pollution and seafood safety. *Environmental Health Perspectives* 123(2), 34-41. https://doi.org/10.1289/ehp.123-A34.

Shao, X., Huang, B., Zhao, Y., Sun, W., Gu, Z. and Qian, W. (2014). Impacts of human activities and sampling strategies on soil heavy metal distribution in a rapidly developing region of China. *Ecotoxicology and Environmental Safety* 104, 1-8. https://doi.org/10.1016/j.ecoenv.2014.02.007.

Shunthirasingham, C., Alexandrou, N., Brice, K.A., Dryfhout-Clark, H., Su, K., Shin, C., Park, R., Pajda, A., Noronha, R. and Hung, H. (2018). Temporal trends of halogenated flame retardants in the atmosphere of the Canadian Great Lakes Basin (2005–2014). *Environmental Science: Processes & Impacts* 20(3), 469-479. https://doi.org/10.1039/C7EM00549K.

Skovgaard, M., Encinas, S.R., Jensen, O.C., Andersen, J.H., Condarco, G. and Jørs, E. (2017). Pesticide residues in commercial lettuce, onion, and potato samples from Bolivia – a threat to public health? *Environmental Health Insights*, 11. https://doi.org/10.1177/1178630217704194.

Stehle, S. and Schulz, R. (2015). Agricultural insecticides threaten surface waters at the global scale. *Proceedings of the National Academy of Sciences* 112(18), 5750-5755. https://doi.org/10.1073/pnas.1500232112.

Strynar, M.J., Lindstrom, A.B., Nakayama, S.F., Egeghy, P.P. and Helfant, L.J. (2012). Pilot scale application of a method for the analysis of perfluorinated compounds in surface soils. *Chemosphere* 86(3), 252-257. https://doi.org/10.1016/J.CHEMOSPHERE.2011.09.036.

Stubleski, J., Salihovic, S., Lind, L., Lind, P.M., Bavel, B. van and Kärrman, A. (2016). Changes in serum levels of perfluoroalkyl substances during a 10-year follow-up period in a large population-based cohort. *Environment International* 95, 86-92. https://doi.org/10.1016/J.ENVINT.2016.08.002.

Terry, P., Towers, C.V., Liu, L.-Y., Peverly, A.A., Chen, J. and Salamova, A. (2017). Polybrominated diphenyl ethers (flame retardants) in mother-infant pairs in the southeastern U.S. *International Journal of Environmental Health Research* 27(3), 205-214. https://doi.org/10.1080/09603123.2017.1332344.

Tornero, V. and Hanke, G. (2016). Chemical contaminants entering the marine environment from sea-based sources: a review with a focus on European seas. *Marine Pollution Bulletin* 112(1–2), 17-38. https://doi.org/10.1016/j.marpolbul.2016.06.091.

Undeman, E., Brown, T.N., McLachlan, M.S. and Wania, F. (2018). Who in the world is most exposed to polychlorinated biphenyls? Using models to identify highly exposed populations. *Environmental Research Letters*. 13(064036), 1-11. https://doi.org/10.1088/1748-9326/aac5fe.

United Nations Environment Programme (2013). *Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport*. http://unep.org/hazardoussubstances/.

United Nations Environment Programme (2016a). *Global Gender and Environment Outlook*. http://wedocs.unep.org/bitstream/handle/20.500.11822/14764/GLOBAL%20GENDER%20AND%20ENVIRONMENT%20OUTLOOK.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2016b). *Marine Plastic Debris and Microplastics. Guidelines and Research to Inspire Action and Guid Policy Changes*. http://wedocs.unep.org/bitstream/handle/20.500.11822/7720/-Marine_plasctic_debris_and_microplastics_Global_lessons_and_research_to_inspire_action_and_guide_policy_change-2016Marine_Plastic_Debris_and_Micropla.pdf?sequence=3&isAllowed=y.

United Nations Environment Programme and Arctic Monitoring and Assessment Program (2018). *Global Mercury Assessment 2018: Review Draft 220518*. https://wedocs.unep.org/bitstream/handle/20.500.11822/25462/GMA%202018-ReviewDraft_250518_CLEAN_SEC.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme and Secretariat of the Stockholm Convention (2017). *Second Global Monitoring Report: Global Monitoring Plan for Persistent Organic Pollutants*. Geneva: Secretariat of the Stockholm Convention. http://chm.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP8/tabid/5309/Default.aspx.

United Nations International Children's Emergency Fund and World Health Organization (2015). *Progress on Sanitation and Drinking Water - 2015 Update and MDG Assessment*. Geneva: World Health Organization. https://www.who.int/water_sanitation_health/publications/jmp-2015-update/en/.

United States Agency for Toxic Substances and Disease Registry (2014). *ATSDR Case Studies in Environmental Medicine Polychlorinated Biphenyls (PCBs) Toxicity*. https://www.atsdr.cdc.gov/csem/pcb/docs/pcb.pdf.

United States Environmental Protection Agency (2013). *America's Children and the Environment*. 3rd edn. https://www.epa.gov/sites/production/files/2015-06/documents/ace3_2013.pdf.

United States Environmental Protection Agency (2014). *Integrated Science Assessment for Lead*. https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=255721#tab-3.

United States Environmental Protection Agency (2017a). Lead (PB) air pollution. https://www.epa.gov/lead-air-pollution. Accessed 4 June 2018.

United States Environmental Protection Agency (2017b). America's children and the environment (ACE): biomonitoring – perfluorochemicals (PFCs). https://www.epa.gov/ace/ace-biomonitoring-perfluorochemicals-pfcs. Accessed 5 June 2018.

United States Environmental Protection Agency (2018). *Chemicals Evaluated for Carcinogenic Potential Annual Cancer Report 2018*. http://npic.orst.edu/chemicals_evaluated.pdf.

United States Environmental Protection Agency (n.d.). Our nation's air 2017. https://gispub.epa.gov/air/trendsreport/2017/#introduction. Accessed 14 February 2018.

van den Berg, M., Kypke K, Kotz A, Tritscher A, Lee SY, Magulova K, Fiedler H, Malisch R. (2017). WHO/UNEP global surveys of PCDDs, PCDFs, PCBs and DDTs in human milk and benefit-risk evaluation of breastfeeding. *Archives of Toxicology* 91, 83-96. https://doi.org/10.1007/s00204-016-1802-z.

Villanueva, C.M., Kogevinas, M., Cordier, S., Templeton, M.R., Vermeulen, R., Nuckols, J.R., Nieuwenhuijsen, M.J. and Levallois, P. (2013). Assessing exposure and health consequences of chemicals in drinking water: current state of knowledge and research needs. *Environmental Health Perspectives* 122(3), 213-221. https://doi.org/10.1289/ehp.1206229.

Wambaugh, J.F., Setzer, R.W., Reif, D.M., Gangwal, S., Mitchell-Blackwood, J., Arnot, J.A., Joliet, O., Frame, A., Rabinowitz, J., Knudsen, T.B., Judson, R.S., Egeghy, P., Vallero, D. and Cohen Hubal, E.A. (2013). High-throughput models for exposure-based chemical prioritization in the expocast project. *Environmental Science & Technology* 47(15), 8479-8488. https://doi.org/10.1021/es400482g.

Wannaz, C., Fantke, P. and Jolliet, O. (2018). Multiscale spatial modeling of human exposure from local sources to global intake. *Environmental Science & Technology* 52(2), 701-711. https://doi.org/10.1021/acs.est.7b05099.

Wannaz, C., Franco, A., Kilgallon, J., Hodges, J. and Jolliet, O. (2018). A global framework to model spatial ecosystems exposure to home and personal care chemicals in Asia. *Science of The Total Environment*. 622-623, 410-420. https://doi.org/10.1016/j.scitotenv.2017.11.315.

Weber, F.-A., Aus Der Beek, T., Carius, A., Grüttner, G., Hickmann, S., Ebert, I., Hein, A., Küster, A., Rose, J., Koch-Jugl, J. and Stolzenberg, H.-C. (2014). *Pharmaceuticals in the Environment – the Global Perspective: Occurrence, Effects, and Potential Cooperative Action under SAICM*. https://www.umweltbundesamt.de/en/publikationen/pharmaceuticals-in-the-environment-the-global.

Webster, E.M., Qian, H., Mackay, D., Christensen, R.D., Tietjen, B. and Zaleski, R. (2016). Modeling human exposure to indoor contaminants: external source to body tissues. *Environmental Science & Technology* 50(16), 8697-8704. https://doi.org/10.1021/acs.est.6b00895.

Weiss, L., Arbuckle, T.E., Fisher, M., Ramsay, T., Mallick, R., Hauser, R., LeBlanc, A., Walker, M., Dumas, P. and Lang, C. (2015). Temporal variability and sources of triclosan exposure in pregnancy. *International Journal of Hygiene and Environmental Health* 218(6), 507-513. https://doi.org/10.1016/J.IJHEH.2015.04.003.

Weithmann, N., Möller, J.N., Löder, M.G.J., Piehl, S., Laforsch, C. and Freitag, R. (2018). Organic fertilizer as a vehicle for the entry of microplastic into the environment. *Science Advances* 4(4), 1-7. http://doi.org/10.1126/sciadv.aap8060.

Wöhrnschimmel, H., MacLeod, M. and Hungerbuhler, K. (2013). Emissions, fate and transport of persistent organic pollutants to the Arctic in a changing global climate. *Environmental Science & Technology* 47(5), 2323-2330. https://doi.org/10.1021/es304646n.

Women in Europe for a Common Future (2016). *Women and Chemicals: The Impact of Hazardous Chemicals on Women. A Thought Starter Based on an Experts' Workshop*. http://www.wecf.eu/download/2016/March/WomenAndChemicals_PublicationIWD2016.pdf.

World Health Organization (2018a). *GEMS/Food – home*. https://extranet.who.int/gemsfood/. Accessed 5 June 2018.

World Health Organization (2018b). 9 out of 10 people worldwide breathe polluted air, but more countries are taking action, 2 May. http://www.who.int/news-room/detail/02-05-2018-9-out-of-10-people-worldwide-breathe-polluted-air-but-more-countries-are-taking-action. Accessed 20 May 2018.

World Health Organization (2018c). *WHO global urban ambient air pollution database (update 2016)*. http://www.who.int/airpollution/data/cities-2016/en/. Accessed 4 June 2018.

Wu, L.-H., Zhang, X.-M., Wang, F., Gao, C.-J., Chen, D., Palumbo, J.R., Guo, Y. and Zeng, E.Y. (2018). Occurrence of bisphenol S in the environment and implications for human exposure: a short review. *Science of The Total Environment* 615, 87-98. https://doi.org/10.1016/j.scitotenv.2017.09.194.

Yang, R., Wei, H., Guo, J. and Li, A. (2012). Emerging brominated flame retardants in the sediment of the Great Lakes. *Environmental Science & Technology* 46(6), 3119-3126. https://doi.org/10.1021/es204141p.

Ye, X., Wong, L.-Y., Kramer, J., Zhou, X., Jia, T. and Calafat, A.M. (2015). Urinary concentrations of bisphenol a and three other bisphenols in convenience samples of U.S. adults during 2000-2014. *Environmental Science & Technology* 49(19), 11834-11839. https://doi.org/10.1021/acs.est.5b02135.

Zhang, G.S. and Liu, Y.F. (2018). The distribution of microplastics in soil aggregate fractions in southwestern China. *Science of the Total Environment* 642: 12-20. https://doi.org/10.1016/j.scitotenv.2018.06.004.

Zhang, X., Zhong, T., Liu L. and Ouyang, X. (2015). Impact of soil heavy metal pollution on food safety in China. *PlosOne*, 7 August. https://doi.org/10.1371/journal.pone.0135182.

Zhang, Y., Jaeglé, L., Thompson, L. and Streets, D.G. (2014). Six centuries of changing oceanic mercury. *Global Biogeochemical Cycles* 28(11), 1251-1261. https://doi.org/10.1002/2014GB004939.

## Chapter 7

Adams, S.M. (2003). Establishing causality between environmental stressors and effects on aquatic ecosystems. *Human and Ecological Risk Assessment: An International Journal* 9(1), 17-35. https://doi.org/10.1080/713609850.

Adams, S.V., Passarelli, M. N. and Newcomb, P. A. (2012). Cadmium exposure and cancer mortality in the Third National Health and Nutrition Examination Survey cohort. *Occupational and Environmental Medicine* 69(2). http://dx.doi.org/10.1136/oemed-2011-100111.

Allen, M.T. and Levy, L.S. (2013). Parkinson's disease and pesticide exposure – a new assessment. *Critical Reviews in Toxicology* 43(6), 515-534. https://doi.org/10.3109/10408444.2013.798719.

Altieri, A.H., Harrison, S.B., Seemann, J., Collin, R., Diaz, R.J. and Knowlton, N. (2017). Tropical dead zones and mass mortalities on coral reefs. *Proceedings of the National Academy of Sciences of the United States of America* 114(14), 3660-3665. https://doi.org/10.1073/pnas.1621517114.

Amankwah, R.K. and Ofori-Sarpong, G. (2014). A lantern retort for small-scale gold extraction. *International Journal of Environmental Protection and Policy* 2(5), 161-167. https://doi.org/10.11648/j.ijepp.20140205.13.

Arbuckle, T.E., Davis, K., Boylan, K., Fisher, M. and Fu, J. (2016). Bisphenol A, phthalates and lead and learning and behavioral problems in Canadian children 6-11 years of age: CHMS 2007-2009. *NeuroToxicology* 54, 89-98. https://doi.org/10.1016/J.NEURO.2016.03.014.

Arbuckle, T.E. and Ritter, L. (2005). Phenoxyacetic acid herbicide exposure for women on Ontario farms. *Journal of Toxicology and Environmental Health, Part A* 68(15), 1359-1370. https://doi.org/10.1080/15287390590953635.

Arias-Andres, M., Klümper, U., Rojas-Jimenez, K. and Grossart, H.-P. (2018). Microplastic pollution increases gene exchange in aquatic ecosystems. *Environmental Pollution* 237, 253-261. https://doi.org/10.1016/j.envpol.2018.02.058.

Bellinger, D.C. (2004). Lead. *Pediatrics* 113, 1016-1022. http://pediatrics.aappublications.org/content/113/Supplement_3/1016.

Bergman, Å., Heindel, J., Jobling, S., Kidd, K. and Zoeller, R.T. (eds) (2013). *State of the Science on Endocrine Disrupting Chemicals-2012: An Assessment of the State of the Science of Endocrine Disruptors Prepared by a Group of Experts for the United Nations Environment Programme*. Geneva: United Nations Environment Programme and World Health Organization. http://www.who.int/ceh/publications/endocrine/en/.

Blankespoor, B., Dasgupta, S., Dhouibi, W., Lagnaoui, A., Meisner, C. and Salah, H. Ben (2009). *Stockpiles of Obsolete Pesticides: Threats to Ecosystems and Biodiversity*. Washington, D.C.: World Bank Research Group. http://siteresources.worldbank.org/INTEAER/Resources/5991606-1251488981857/Das_Gupta_ObsoletePesticides_BiodiversityEcosystems.Tunisia_Note_Aug09.pdf.

Bloom, M.S., Whitcomb, B.W., Chen, Z., Ye, A., Kannan, K. and Buck Louis, G.M. (2015). Associations between urinary phthalate concentrations and semen quality parameters in a general population. *Human Reproduction* 30(11), 2645-2657. https://doi.org/10.1093/humrep/dev219.

Bose-O'Reilly, S., McCarty, K.M., Steckling, N., and Lettmeier, B. (2010). Mercury exposure and children's health. *Current Problems in Pediatric and Adolescent Health Care* 40(8), 186-215. http://doi.org/10.1016/j.cppeds.2010.07.002.

Braun, J.M., Muckle, G., Arbuckle, T., Bouchard, M.F., Fraser, W.D., Ouellet, E., Séguin, J.R., Oulhote, Y., Webster, G.M. and Lanphear, B.P. (2017). Associations of prenatal urinary bisphenol a concentrations with child behaviors and cognitive abilities. *Environmental Health Perspectives* 125(06). https://doi.org/10.1289/EHP984.

Breitburg, D., Levin, L.A. Oschilies, A., Grégoire, M., Chavez, F.P., Conley, D.J., Garçon, V., Séguin, J.R., Oulhote, Y., Webster, G.M. and Lanphear, B.P. (2018). Declining oxygen in the global ocean and coastal waters. *Science* 359(6371), 1-11. http://doi.org/10.1126/science.aam7240.

Broughton, E. (2005). The Bhopal disaster and its aftermath: a review. *Environmental Health* 4(6), 1-6. https://doi.org/10.1186/1476-069x-4-6.

Cantin, N., Negri, A. and Willis, B. (2007). Photoinhibition from chronic herbicide exposure reduces reproductive output of reef-building corals. *Marine Ecology Progress Series* 344, 81-93. https://doi.org/10.3354/meps07059.

Carman, H.A. (2017). Multiple chemical sensitivity – two illustrative case reports. *Current Allergy & Clinical Immunology* 30(1), 1-4. https://journals.co.za/docserver/fulltext/caci_v30_n1_a7.pdf?expires=1535291261&id=id&accname=guest&checksum=E62AB9AF1336DEF5807FE87D3F133F40.

Carpenter, D.O. and Miller, P.K. (2011). Environmental contamination of the Yupik people of St. Lawrence Island, Alaska. *Journal of Indigenous Research Full Circle Lawrence Island Alaska Journal of Indigenous Research* 1(1), 1-4. http://digitalcommons.usu.edu/kicjir.

Chagnon, M., Kreutzweiser, D., Mitchell, E.A.D., Morrissey, C.A., Dominique, A.N. and van der Sluijs, J.P. (2015). Risks of large-scale use of systemic insecticides to ecosystem fucntioning and services. *Environmental Science and Pollution Research* 22(1), 119-134. https://link.springer.com/article/10.1007/s11356-014-3277-x.

Chatham-Stephens, K., Caravanos, J., Ericson, B., Sunga-Amparo, J., Susilorini, B., Sharma, P., Landrigan, P.J. and Fuller, R. (2013). Burden of disease from toxic waste sites in India, Indonesia, and the Philippines in 2010. *Environmental Health Perspectives* 121(7), 791-796. https://doi.org/10.1289/ehp.1206127.

Chatham-Stephens, K., Caravanos, J., Ericson, B., Landrigan, P. and Fuller, R. (2014). The pediatric burden of disease from lead exposure at toxic waste sites in low and middle income countries. *Environmental Research* 132, 379-383. https://doi.org/10.1016/j.envres.2014.04.018.

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J. and Galloway, T.S. (2013). Microplastic ingestion by zooplankton. *Environmental Science & Technology* 47, 6646-6655. https://doi.org/10.1021/es400663f.

Collins, M.B., Munoz, I. and JaJa, J. (2016). Linking 'toxic outliers' to environmental justice communities. *Environmental Research Letters* 11, 1-9. https://doi.org/10.1088/1748-9326/11/1/015004.

Cremonese, C., Piccoli, C., Pasqualotto, F., Clapauch, R., Koifman, R.J., Koifman, S. and Freire, C. (2017). Occupational exposure to pesticides, reproductive hormone levels and sperm quality in young brazilian men. *Reproductive Toxicology* 67, 174-185. https://doi.org/10.1016/j.reprotox.2017.01.001.

Danovaro, R., Bongiorni, L., Corinaldesi, C., Giovannelli, D., Damiani, E., Astolfi, P., Greci, L. and Pusceddu, A. (2008). Sunscreens cause coral bleaching by promoting viral infections. *Environmental Health Perspectives* 116(4), 441-447. https://doi.org/10.1289/ehp.10966.

de Roos, A.J., Davis, S., Colt, J.S., Blair, A., Airola, M., Severson, R.K., Cozen, W., Cerhan, J.R., Hartge, P., Nuckols, J.R. and Ward, M.H. (2010). Residential proximity to industrial facilities and risk of non-hodgkin lymphoma. *Environmental Research*. 110(1), 70-78. https://doi.org/10.1016/J.ENVRES.2009.09.011.

de Souza Machado, A.A., Kloas, W., Zarfl, C., Hempel, S. and Rillig, M.C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. *Global Change Biology* 24(4), 1405-1416. https://doi.org/10.1111/gcb.14020.

Di Renzo, G.C., Conry, J.A., Blake, J., DeFrancesco, M.S., DeNicola, N., Martin, J.N., McCue, K.A., Richmond, D., Shah, A., Sutton, P., Woodruff, T.J., van der Poel, S.Z. and Giudice, L.C. (2015). International Federation of Gynecology and Obstetrics opinion on reproductive health impacts of exposure to toxic environmental chemicals. *International Journal Gynecology and Obstetrrics* 131(3), 219-25. https://doi.org/10.1016/j.ijgo.2015.09.002.

Díaz, R.J. and Rosenberg, R. (2011). Introduction to environmental and economic consequences of hypoxia. *International Journal of Water Resources Development* 27(1), 71-82. https://doi.org/10.1080/07900627.2010.531379.

Downs, C.A., Kramarsky-Winter, E., Segal, R., Fauth, J., Knutson, S., Bronstein, O., Ciner, F.R., Jeger, R., Lichtenfeld, Y., Woodley, C.M., Pennington, P., Cadenas, K., Kushmaro, A. and Loya, Y. (2016). Toxicopathological effects of the sunscreen UV filter, oxybenzone (benzophenone-3), on coral planulae and cultured primary cells and its environmental contamination in hawaii and the U.S. Virgin Islands. *Archives of Environmental Contamination and Toxicology* 70(2), 265-288. https://doi.org/10.1007/s00244-015-0227-7.

Essel, R., Engel, L., Carus, M. and Heinrich Ahrens, R. (2015). *Sources of Microplastics Relevant to Marine Protection in Germany*. Werner, S. (ed.). Dessau-Roßlau: German Environment Agency. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_64_2015_sources_of_microplastics_relevant_to_marine_protection_1.pdf.

European Commission (2011). *Toxicity and Assessment of Chemical Mixtures.* Scientific Committee on Health and Environmental Risks. https://doi.org/10.2772/21444.

European Commission (2018). Major Accident Reporting System (eMARS). https://ec.europa.eu/knowledge4policy/projects-activities/major-accident-reporting-system-emars_en. Accessed 16 February 2019.

Food and Agriculture Organization of United Nations (2011). *2010-11 The State of Food and Agriculture: Women in Agriculture - Closing the Gender Gap for Development*. http://www.fao.org/3/a-i2050e.pdf.

García, A.M. (2003). Pesticide exposure and women's health. *American Journal of Industrial Medicine* 44(6), 584-594. https://doi.org/10.1002/ajim.10256.

GBD Risk Factors Collaborators (2016). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2015: a systematic analysis for the global burden of disease study 2015. *The Lancet* 388(10053), 1659-1724. https://doi.org/10.1016/S0140-6736(16)31679-8.

Global Alliance on Health and Pollution (2013). *The Poisoned Poor: Toxic Chemicals Exposures in Low-and Middle-Income Countries*. http://gahp.net/wp-content/uploads/2017/02/GAHPPoisonedPoor_Report-Sept-2013.pdf.

Goldman, L. and Tran, N. (2002). *Toxics and Poverty: The Impact of Toxic Substances on the Poor in Developing Countries*. Washington, D.C.: World Bank. http://siteresources.worldbank.org/INTPOPS/Publications/20486400/TOXICStext917w.pdf.

Grandjean, P. and Landrigan, P. (2006). Developmental neurotoxicity of industrial chemicals. *The Lancet* 368, 1-12. https://doi.org/10.1016/S0140-6736(06)69665-7.

Grandjean, P. and Landrigan, P.J. (2014). Neurobehavioural effects of developmental toxicity. *The Lancet. Neurology* 13(3), 330-338. https://doi.org/10.1016/S1474-4422(13)70278-3.

Grimalt, J.O., Ferrer, M. and Macpherson, E. (1999). The mine tailing accident in Aznalcollar. *Science of The Total Environment 242 (1-3)*, 3-11. https://doi.org/10.1016/S0048-9697(99)00372-1.

Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D. and de Kroon, H. (2017). More than 75 per cent decline over 27 years in total flying insect biomass in protected areas. *PLOS One* 12(10), 1-21. https://doi.org/10.1371/journal.pone.0185809.

Hämäläinen, J., Takala, J. and Kiat, T.B. (2017). *Global Estimates of Occupational Accidents and Work-related Illnesses 2017*. Singapore: Workplace Safety and Health Institute. http://www.icohweb.org/site/images/news/pdf/Report%20Global%20Estimates%20of%20Occupational%20Accidents%20and%20Work-related%20Illnesses%202017%20rev1.pdf.

Hatje, V., Pedreira, R.M.A., de Rezende, C.E., Schettini, C.A.F., de Souza, G.C., Marin, D.C. and Hackspacher, P.C. (2017). The environmental impacts of one of the largest tailing dam failures worldwide. *Scientific Reports* 7, 1-13. https://doi.org/10.1038/s41598-017-11143-x.

Health Canada (2013). *Final Human Health State of the Science Report on Lead*. https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/environmental-contaminants/final-human-health-state-science-report-lead.html.

Heindel, J.J., vom Saal, F.S., Blumberg, B., Bovolin, P., Calamandrei, G., Ceresini, G., Cohn, B.A., Fabbri, E., Gioiosa, L., Kassotis, C., Legler, J., La Merrill, M., Rizzir, L., Machtinger, R., Mantovani, A., Mendez, M.A., Montanini, L., Molteni, L., Nagel, S.C., Parmigiani, S., Panzica, G., Paterlini, S., Pomatto, V., Ruzzin, J., Sartor, G., Schug, T.T., Street, M.E., Suvorov, A., Volpi, R., Zoeller, R.T. and Palanza, P. (2015). Parma consensus statement on metabolic disorders. *Environmental Health* 14(1),54. https://doi.org/10.1186/s12940-015-0042-7.

Hu, X.F, Laird, B.D. and Chan, H.M. (2017). Mercury diminishes the cardiovascular protective effect of omega-3 polyunsaturated fatty acids in the modern diet of Inuit in Canada. *Environmental Research* 152, 470-477. https://doi.org/10.1016/j.envres.2016.06.001.

Imran, M., Das, K.R., Naik, M.M. (2019). Co-selection of multi-antibiotic resistance in bacterial pathogens in metal and microplastic contaminated environments: an emerging health threat. *Chemosphere* 215, 846-857. https://doi.org/10.1016/j.chemosphere.2018.10.114.

Institute for Health Metrics and Evaluation (2019). Global health data exchange: GBD results tool. http://ghdx.healthdata.org/gbd-results-tool. Accessed 14 February 2019.

International Agency for Research on Cancer (2012). GLOBOCAN 2012: estimated cancer incidence, mortality and prevalence worldwide. http://globocan.iarc.fr/Pages/fact_sheets_cancer.aspx. Accessed 7 August 2016.

International Agency for Research on Cancer (2018). *Agents Classified by the IARC Monographs: Volumes 1-123.* https://monographs.iarc.fr/ENG/Classification/ClassificationsAlphaOrder.pdf.

International Association of Oil and Gas Producers (2017). Safety performance in 2017: fewer fatalities than ever – but still not good enough, 4 July. https://www.iogp.org/blog/oil-and-gas-safety/fewer-fatalities-in-2017/. Accessed 16 February 2019.

International Institute for Environment and Development (2002). *Breaking New Ground: Mining, Minerals and Sustainable Development*. https://www.iied.org/mmsd-final-report.

International Labor Organization (2005) *Facts on Safety at Work*. https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms_067574.pdf.

International Labour Organization (2011). *Children in Hazardous Work: What We Know, What We Need to Do*. https://www.ilo.org/wcmsp5/groups/public/@dgreports/@dcomm/@publ/documents/publication/wcms_155428.pdf.

International Labour Organization (2013a). *Safety and Health in the Use of Chemicals at Work: World Day for Safety and Health at Work 28 April 2014*. https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_235085.pdf.

International Labour Organization (2013b). *Marking Progress Against Child Labour: Global Estimates and Trends 2000-2012*. https://www.ilo.org/wcmsp5/groups/public/@ed_norm/@ipec/documents/publication/wcms_221513.pdf.

Israel, B. (2013). Long-lasting chemicals may harm sea turtles, 14 March. *Scientific American, .* https://www.scientificamerican.com/article/long-lasting-chemicals-may-harm-sea-turtles/. Accessed 16 February 2019.

Jerie, S. (2016). Occupational risks associated with solid waste management in the informal sector of Gweru, Zimbabwe. Journal of Environmental and Public Health 2016, 1-14. http://dx.doi.org/10.1155/2016/9024160.

Johnston, E.L., Mayer-Pinto, M. and Crowe, T.P. (2015). Review: chemical contaminant effects on marine ecosystem functioning. Journal of Applied Ecology 52(1), 140-149. https://doi.org/10.1111/1365-2664.12355.

Kidd, K.A., Blanchfield, P.J., Mills, K.H., Palace, V.P., Evans, R.E., Lazorchak, J.M. and Flick, R.W. (2007). Collapse of a fish population after exposure to a synthetic estrogen. *Proceedings of the National Academy of Sciences of the United States of America* 104(21), 8897-8901. https://doi.org/10.1073/pnas.0609568104.

Kim, I., Kim, M.-H. and Lim, S. (2015). Reproductive hazards still persist in the microelectronics industry: increased risk of spontaneous abortion and menstrual aberration among female workers in the microelectronics industry in South Korea. *PLOS One* 10(5), 1-10. https://doi.org/10.1371/journal.pone.0123679.

Kortenkamp, A., Backhaus, T. and Faust, M. (2009). *State of the Art Report on Mixture Toxicity*. http://ec.europa.eu/environment/chemicals/effects/pdf/report_mixture_toxicity.pdf.

Laetz, C.A., Baldwin, D.H., Collier, T.K., Hebert, V., Stark, J.D. and Scholz, N.L. (2009). The synergistic toxicity of pesticide mixtures: implications for risk assessment and the conservation of endangered Pacific salmon. *Environmental Health Perspectives* 117(3), 348-353. https://doi.org/10.1289/ehp.0800096.

Landrigan, P.J., Fuller, R., Acosta, N.J.R., Adeyi, O., Arnold, R., Basu, N.N., Baldé, A.B., Bertollini, R., Bose-O'Reilly, S., Boufford, J.I., Breysse, P.N., Chiles, T., Mahidol, C., Coll-Seck, A.M., Cropper, M.L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. V, McTeer, M.A., Murray, C.J.L., Ndahimananjara, J.D., Perera, F., Potočnik, J., Preker, A.S., Ramesh, J., Rockström, J., Salinas, C., Samson, L.D., Sandilya, K., Sly, P.D., Smith, K.R., Steiner, A., Stewart, R.B., Suk, W.A., van Schayck, O.C.P., Yadama, G.N., Yumkella, K. and Zhong, M. (2017). The *Lancet* commission on pollution and health. *The Lancet*. 391(10119), 462-512. https://doi.org/10.1016/S0140-6736(17)32345-0.

Lanphear, B.P. (2015). The impact of toxins on the developing brain. *Annual Review of Public Health* 36(1), 211-230. https://doi.org/10.1146/annurev-publhealth-031912-114413.

Lidsky, T.I. and Schneider, J.S. (2003). Lead neurotoxicity in children: basic mechanisms and clinical correlates. *Brain* 126(1), 5-19. https://doi.org/10.1093/brain/awg014.

Longnecker, M.P., Klebanoff, M.A., Zhou, H. and Brock, J.W. (2001). Association between maternal serum concentration of the DDT metabolite DDE and preterm and small-for-gestational-age babies at birth. *The Lancet* 358(9276), 110-114. https://doi.org/10.1016/S0140-6736(01)05329-6.

McCarty, J.F. (2018). Lake Erie dead zone threatens Cleveland drinking water, 25 July. *The Plain Dealer*. https://www.cleveland.com/metro/index.ssf/2018/07/lake_erie_dead_zone_poses_annu.html. Accessed 17 February 2019.

Malaj, E., von der Ohe, P.C., Grote, M., Kühne, R., Mondy, C.P., Usseglio-Polatera, P., Brack, W. and Schäfer, R.B. (2014). Organic chemicals jeopardize the health of freshwater ecosystems on the continental scale. *Proceedings of the National Academy of Sciences of the United States of America* 111(26), 9549-9554. https://doi.org/10.1073/pnas.1321082111.

Martenies, S.E. and Perry, M.J. (2013). Environmental and occupational pesticide exposure and human sperm parameters: a systematic review. *Toxicology* 307, 66–73. https://doi.org/10.1016/j.tox.2013.02.005.

Marushka, L., Batal, M., David, W., Schwartz, H., Ing, A., Fediuk, K., Sharp, D., Black, A., Tikhonov, C. and Chan, H.M. (2017). Association between fish consumption, dietary omega-3 fatty acids and persistent organic pollutants intake, and type 2 diabetes in 18 first nations in Ontario, Canada. *Environmental Research* 156, 725-737. http://dx.doi.org/10.1016/j.envres.2017.04.034.

Meek, B., Boobis, A.R., Crofton, K.M., Heinemeyer, G., Raaij, M. Van and Vickers, C. (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regulatory Toxicology and Pharmacology* 60(2), S1-S14. https://doi.org/10.1016/j.yrtph.2011.03.010.

Mihailidou, E.K., Antoniadis, K.D. and Assael, M.J. (2012). The 319 major industrial accidents since 1917. *International Review of Chemical Engineering* 4(6), 529-540. http://www.hristov.com/jordan/pdfs/The%20319%20Major%20Industrial%20Accidents%20Since%201917-IRECHE_VOL_4_N_6.pdf.

Miranda-Contreras, L., Cruz, I., Osuna, J.A., Gómez-Pérez, R., Berrueta, L., Salmen, S., Colmenares, M., Barreto, S., Balza, A., Morales, Y., Zavala, L., Labarca, E., García, N., Sanchez, B., Contreras, C.A. and Andrade, H. (2015). [Effects of occupational exposure to pesticides on semen quality of workers in an agricultural community of Merida state, Venezuela]. *Investigacion Clinica* 56(2), 123-36. http://www.ncbi.nlm.nih.gov/pubmed/26299054.

Moffat, C., Pacheco, J.G., Sharp, S., Samson, A.J., Bollan, K.A., Huang, J., Buckland, S.T. and Connolly, C.N. (2015). Chronic exposure to neonicotinoids increases neuronal vulnerability to mitochondrial dysfunction in the bumblebee (*Bombus terrestris*). *Federation of American Societies for Experimental Biology Journal* 29, 2112-2119. https://doi.org/10.1096/fj.14-267179.

Nambirajan, K., Muralidharan, S., Roy, A.A. and Manomani, S. (2018). Residues of diclofenac in tissues of vultures in India: a post-ban scenario. *Archives of Environmental Contamination and Toxicology* 74(2), 292-297. https://doi.org/10.1007/s00244-017-0480-z.

Needleman, H. (2004). Lead poisoning. *Annual Review of Medicine* 55(1), 209-222. https://doi.org/10.1146/annurev.med.55.091902.103653.

Norwegian Institute for Water Research (2018). Microplastics in agricultural soils: a reason to worry? 1 February. https://www.niva.no/en/news/microplastics-in-agricultural-soils-a-reason-to-worry. Accessed 9 September 2018.

Organisation for Economic Co-operation and Development (2011). *WHO OECD ILSI/HESI International Workshop on Risk Assessment of Combined Exposures to Multiple Chemicals*. Workshop report. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2011)10&doclanguage=en.

Organisation for Economic Co-operation and Development (2019). The chemical accidents programme. http://www.oecd.org/env/ehs/chemical-accidents/thechemicalaccidentsprogramme.htm. Accessed 16 February 2019.

Osachoff, H.L., Mohammadali, M., Skirrow, R.C., Hall, E.R., Brown, L.L.Y., van Aggelen, G.C., Kennedy, C.J. and Helbing, C.C. (2014). Evaluating the treatment of a synthetic wastewater containing a pharmaceutical and personal care product chemical cocktail: compound removal efficiency and effects on juvenile rainbow trout. *Water Research* 62, 271-280. https://doi.org/10.1016/j.watres.2014.05.057.

Ostojić, N. (2016). *Health Risks and Impacts of Hazardous Chemicals in Products on Women and Children*. Belgrade: United Nations Development Programme Country Office in Serbia. http://www.alhem.rs/wp-content/uploads/2015/12/gender-srpski.pdf.

Payton, M., Riggs, K.M., Spiro Iii, A., Weiss, S.T., Mayer, J., Riggs, K.M., Spiro Iii, A. and Weiss, S.T. (1998). Relations of bone and blood lead to cognitive function: the VA normative aging study. *Neurotoxicology and Teratology* 20(1), 19-27. https://pdfs.semanticscholar.org/689b/e10901f4e7eb7b406bb406b5886f70c5fec9.pdf.

Pesticide Action Network Asia and the Pacific (2017). *The Price of Indonesia's Palm Oil: Vulnerable and Exploited Women Workers*. http://files.panap.net/resources/The-Price-of-Indonesias-Palm-Oil.pdf.

Prüss-Ustün, A., Vickers, C., Haefliger, P. and Bertollini, R. (2011). Knowns and unknowns on burden of disease due to chemicals: a systematic review. *Environmental Health* 10(9), 1-15. https://doi.org/10.1186/1476-069X-10-9.

Prüss-Ustün, A., Wolf, J., Corvalán, C., Bos, R. and Neira, M. (2016). *Preventing Disease through Healthy Environments: A Global Assessment of the Burden of Disease from Environmental Risks*. Geneva: World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/204585/9789241565196_eng.pdf;jsessionid=DB60589B14DCAD17C29FCC253F00B795?sequence=1.

Rather, I.A., Koh, W.Y., Paek, W.K. and Lim, J. (2017). The sources of chemical contaminants in food and their health implications. *Frontiers in Pharmacology* 8(830), 1-8. https://doi.org/10.3389/fphar.2017.00830.

Rauh, V.A., Landrigan, P.J. and Claudio, L. (2008). Housing and health: intersection of poverty and environmental exposures. *Annals of the New York Academy of Sciences* 1136(1), 276-288. https://doi.org/10.1196/annals.1425.032.

Review on Antimicrobial Resistance (2016). *Tackling Drug-Resistant Infections Globally: Final Report and Recommendations*. https://amr-review.org/sites/default/files/160518_Final%20paper_with%20cover.pdf.

Rice, D. and Barone, S. (2000). Critical periods of vulnerability for the developing nervous system: evidence from humans and animal models. *Environmental Health Perspectives* 108(3), 511-33. https://doi.org/10.1289/ehp.00108s3511.

Rice, M. (2009). Revealed... the 515 chemicals women put on their bodies every day, 21 November. http://www.dailymail.co.uk/femail/beauty/article-1229275/Revealed--515-chemicals-women-bodies-day.html. Accessed 12 August 2016.

Rillig, M.C. and Bonkowski, M. (2018). Microplastic and soil protists: a call for research. *Environmental Pollution* 341, 1128-1131. https://doi.org/10.1016/j.envpol.2018.04.147.

Rim, K.-T. (2017). Reproductive toxic chemicals at work and efforts to protect workers' health: a literature review. *Safety and Health at Work* 8(2), 143-150. https://doi.org/10.1016/J.SHAW.2017.04.003.

Rios, L.M., Jones, P.R., Moore, C. and Narayan, U.V (2010). Quantitation of persistent organic pollutants adsorbed on plastic debris from the Northern Pacific Gyre's 'eastern garbage patch'. *Journal of Environmental Monitoring* 12(12), 2226-2236. https://doi.org/10.1039/C0EM00239A.

Risher J.F., Todd, G.D., Meyer, D. and Zunker, C. (2010). The elderly as a sensitive population in environmental exposures: making the case. In *Reviews of Environmetal Contamination and Toxicology* Volume 207. Whitacre, D.M. (ed.). New York, NY: Springer. 95-157. http://doi.org/10.1007/978-1-4419-6406-9_2.

Rockefeller Foundation (2013). *Health Vulnerabilities of Informal Workers Problem Statement and Key Messages*. https://assets.rockefellerfoundation.org/app/uploads/20130528214745/Health-Vulnerabilities-of-Informal-Workers.pdf.

Rossi, S. and Pitidis, A. (2018). Multiple chemical sensitivity: review of the state of the art in epidemiology, diagnosis, and future perspectives. *Journal of Occupational and Environmental Medicine* 60(2), 138-146. https://doi.org/10.1097/JOM.0000000000001215.

Ruiz, D., Becerra, M., Jagai, J.S., Ard, K. and Sargis, R.M. (2018). Disparities in environmental exposures to endocrine-disrupting chemicals and diabetes risk in vulnerable populations. *Diabetes Care* 41(1), 193-205. https://doi.org/10.2337/dc16-2765.

Rushton, L., Hutchings S.J., Fortunato, L., Young, C., Evans, G.S., Brown, T., Bevan, R., Slack, R., Holmes, P., Bagga, S., Cherrie, J.W. and Van Tongeren, M. (2012). Occupational cancer burden in Great Britain. *British Journal of Cancer*, Suppl 1, S3-7. https://doi.org/10.1038/bjc.2012.112.

Santana, V. and Rubeiro, F. (2011). Occupational cancer burden in developing countries and the problem of informal workers. *Environmental Health* 10, Suppl 10. https://doi.org/10.1186/1476-069X-10-S1-S10.

Schooley, T., Weaver, M.J., Mullins, D. and Eick, M. (2008). The history of lead arsenate use in apple production: comparison of its impact in Virginia with other states. Journal of Pesticide Safety Education 10, 22-53. https://aapse.wildapricot.org/resources/Documents/AAPSE%20Publications/JPSE/ARTICLES/1/public/1-195-1-PB.pdf.

Science Communication Unit, University of the West of England (2013). *Soil Contamination: Impacts on Human Health Science for Environment Policy*. Bristol: European Commission. http://ec.europa.eu/environment/integration/research/newsalert/pdf/IR5_en.pdf.

Secretariat of the Strategic Approach to International Chemicals Management Secretariat (2016). *Gender and the Sound Management of Chemicals and Waste: Prepared for the Intersessional Process Considering the Strategic Approach and the Sound Management of Chemicals and Waste beyond 2020.* http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_6_gender_document.pdf.

Secretariat of the Stockholm Convention (2017). *Report of the Persistent Organic Pollutants Review Committee on the Work of its Thirteenth Meeting - Addendum: Risk Management Evaluation on Dicofol*. UNEP/POPS/POPRC.13/7/Add.1. http://www.pops.int/Default.aspx?tabid=5965.

Secretariat of the Stockholm Convention (2018). *Report of the Persistent Organic Pollutants Review Committee on the Work of its Fourteenth Meeting - Addendum to the Risk Management Evaluation on Perfluorooctanoic Acid (PFOA) its Salts and PFOA-related Compounds.* UNEP/POPS/POPRC.14/6/Add.2. http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC14/Overview/tabid/7398/Default.aspx.

Setälä, O., Fleming-Lehtinen, V. and Lehtiniemi, M. (2012). Ingestion and transfer of microplastics in the planktonic food web. *Environmental Pollution* 185, 77-83. https://doi.org/10.1016/j.envpol.2013.10.013.

Singer, A.C., Shaw, H., Rhodes, V. and Hart, A. (2016). Review of antimicrobial resistance in the environment and Its relevance to environmental regulators. *Frontiers in Microbiology* 7(1728), 1-22. https://doi.org/10.3389/fmicb.2016.01728.

Starbuck, A. and White, R. (2016). Living in the Shadow of Danger: Poverty, Race, and Unequal Chemical Facility Hazards. Washington D.C.: Center for Effective Government. https://www.foreffectivegov.org/sites/default/files/shadow-of-danger-highrespdf.pdf.

State of Hawaii (2018). Senate bill no. 2571 related to water pollution. https://www.capitol.hawaii.gov/session2018/bills/SB2571_.HTM. 18 February 2019

Stein, J., Schettler, T., Rohrer, B. and Valenti, M. (2008). *Environmental Threats to Healthy Aging: With a Closer Look at Alzheimer's & Parkinson's Diseases*. Myers, N. (ed.). Boston: Greater Boston Physicians for Social Responsibility and Science and Environmental Health Network. http://www.agehealthy.org/pdf/GBPSRSEHN_HealthyAging1017.pdf.

Steinemann, A. (2016). Fragranced consumer products: exposures and effects from emissions. *Air Quality, Atmosphere & Health* 9(8), 861-866. https://doi.org/10.1007/s11869-016-0442-z.

Steinemann, A. (2018a). National prevalence and effects of multiple chemical sensitivities. *Journal of Occupational and Environmental Medicine* 60(3), e152-e156. https://doi.org/10.1097/JOM.0000000000001272.

Steinemann, A. (2018b). Prevalence and effects of multiple chemical sensitivities in Australia. *Preventive Medicine Reports* 10, 191-194. https://doi.org/10.1016/J.PMEDR.2018.03.007.

Straub, L., Villamar-Bouza, L., Bruckner, S., Chantawannakul, P., Gauthier, L., Khongphinitbunjong, K., Retschnig, G., Troxler, A., Vidondo, B., Neumann, P. and Williams, G.R. (2016). Neonicotinoid insecticides can serve as inadvertent insect contraceptives. *Proceedings of the Royal Society B Biological Sciences* 283, 1-8. https://doi.org/10.1098/rspb.2016.0506.

Swackhamer, D.L., Needham, L.L., Powell, D.E. and Muir, D.C.G. (2009). Use of measurement data in evaluating exposure of humans and wildlife to POPs/PBTs. *Integrated Environmental Assessment and Management* 5(4), 638. https://doi.org/10.1897/IEAM_2008-094.1.

Tellez-Plaza, M., Guallar, E., Howard, B. V., Umans, J.G. Francesconi, K.A., Goessler, W., Silbergeld, E.K., Devereux, R.B. and Navas-acien, A. (2013). Cadmium exposure and incident cardiovascular disease. *Epidemiology* 24(3), 421. http://doi.org/10.1097/EDE.0b013e31828b0631.

Thrupp, L.A. (1991). Sterilization of workers from pesticide exposure: the causes and consequences of DBCP-induced damage in Costa Rica and beyond. *International Journal of Health Services* 21(4), 731-757. https://doi.org/10.2190/25B9-QFMV-Y28P-L736.

Turner, M.C., Wigle, D.T. and Krewski, D. (2010). Residential pesticides and childhood leukemia: a systematic review and meta-analysis. *Environmental Health Perspectives* 118(1), 33-41. https://doi.org/10.1289/ehp.0900966.

Undeman, E., Brown, T.N., McLachlan, M.S. and Wania, F. (2018). Who in the world is most exposed to polychlorinated biphenyls? Using models to identify highly exposed populations. *Environmental Research Letters* 13(6), 1-11. https://doi.org/10.1088/1748-9326/aac5fe.

United Nations Development Programme (2007). *Gender Mainstreaming: The Why and How of Mainstreaming Gender in Chemicals Management*. http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/chemicals-management/chemicals-management-the-why-and-how-of-mainstreaming-gender/Chemicals Management and Gender Mainstreaming.pdf.

United Nations Development Programme (2011). *Chemicals and Gender*. http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/chemicals-management/chemicals-and-gender/2011 Chemical&Gender.pdf.

United Nations Environment Programme (2015). *The Montreal Protocol and Human Health: How Global Action Protects Us from the Ravages of Ultraviolet Radiation*. http://www.unep.fr/ozonaction/information/mmcfiles/7738-e-TheMontrealProtocolandHumanHealth.pdf.

United Nations Environment Programme (2016). *Global Gender and Environment Outlook*. http://wedocs.unep.org/bitstream/handle/20.500.11822/14764/GLOBAL%20GENDER%20AND%20ENVIRONMENT%20OUTLOOK.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2017a). *Antimicrobial Resistance: Investigating the Environmental Dimension.* http://wedocs.unep.org/bitstream/handle/20.500.11822/22263/Frontiers_2017_CH1_EN.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2017b). *Overview Report II: An Overview of Current Scientific Knowledge on the Life Cycles, Environmental Exposures, and Environmental Effects of Select Endocrine Disrupting Chemicals (EDCs) and Potential EDCs*. https://wedocs.unep.org/bitstream/handle/20.500.11822/25634/edc_report2.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme and United Nations Office for the Coordination of Humanitarian Affairs (2000). *Spill of Liquid and Suspended Waste at the Aurul S.A. Retreatment Plant in Baia Mare. Assessment Mission: Romania, Hungary, Federal Republic of Yugoslavia.* https://reliefweb.int/sites/reliefweb.int/files/resources/43CD1D010F030359C12568CD00635880-baiamare.pdf.

United States Agency for Toxic Substances and Disease registry (2018). *Framework for Assessing Health Impacts of Multiple Chemicals and Other Stressors (Update)*. https://www.atsdr.cdc.gov/interactionprofiles/ip-ga/ipga-p.pdf.

United States Centers for Disease Control and Prevention (2014). *Prevalence of Autism Spectrum Disorder Among Children Aged 8 Years — Autism and Developmental Disabilities Monitoring Network, 11 Sites, United States, 2010*. Morbidity and Mortality Weekly Report. Atlanta, GA: United States Department of Health and Human Services Centers for Disease Control and Prevention. https://www.cdc.gov/mmwr/pdf/ss/ss6302.pdf.

United States Environmental Protection Agency (2015). Updating ozone calculations and emissions profiles for use in the atmospheric and health effects framework model. https://www.epa.gov/sites/production/files/2015-07/documents/updating_ozone_calculations_and_emissions_profiles_for_use_in_the_atmospheric_and_health_effects_framework_model.pdf.

United States Environmental Protection Agency (2018). Superfund. https://www.epa.gov/superfund. Accessed 8 September 2018.

United States Geological Survey (2018). Nutrient loading for the Mississippi River and subbasins. https://nrtwq.usgs.gov/mississippi_loads/#/. Accessed 17 February 2019.

United States National Toxicology Program (2012). *NTP Monograph on Health Effects of Low-Level Lead*. https://ntp.niehs.nih.gov/ntp/ohat/lead/final/monographhealtheffectslowlevellead_newissn_508.pdf.

van Dijk, A., Slaper, H., den Outer, P.N., Morgenstern, O., Braesicke, P., Pyle, J.A., Garny, H., Stenke, A., Dameris, M., Kazantzidis, A., Tourpali, K. and Bais, A.F. (2013). Skin cancer risks avoided by the Montreal Protocol – worldwide modeling integrating coupled climate-chemistry models with a risk model for UV. *Photochemisty and Photobioloy* 89(1), 234-246. https://doi.org/10.1111/j.1751-1097.2012.01223.x.

Vandenberg, L.N., Colborn, T., Hayes, T.B., Heindel, J.J., Jacobs, D.R., Lee, D.-H., Shioda, T., Soto, A.M., vom Saal, F.S., Welshons, W. V., Zoeller, R.T. and Myers, J.P. (2012). Hormones and endocrine-disrupting chemicals: low-dose effects and nonmonotonic dose responses. *Endocrine Reviews* 33(3), 378-455. https://doi.org/10.1210/er.2011-1050.

Vasyukova, I., Gusev, A. and Tkachev, A. (2015). Reproductive toxicity of carbon nanomaterials: a review. *IOP Conference Series* 98, 1-7. http://iopscience.iop.org/article/10.1088/1757-899X/98/1/012001/pdf.

Vélez, M.P., Arbuckle, T.E. and Fraser, W.D. (2015a). Maternal exposure to perfluorinated chemicals and reduced fecundity: the MIREC study. *Human Reproduction* 30(3), 701-709. https://doi.org/10.1093/humrep/deu350.

Vélez, M.P., Arbuckle, T.E. and Fraser, W.D. (2015b). Female exposure to phenols and phthalates and time to pregnancy: the maternal-infant research on environmental chemicals (MIREC) study. *Fertility and Sterility* 103(4), 1011-1020. https://doi.org/10.1016/j.fertnstert.2015.01.005.

Wäger, P.A., Schluep, M., Müller, E. and Gloor, R. (2012). RoHS regulated substances in mixed plastics from waste electrical and electronic equipment. *Environmental Science & Technology* 46(2), 628-635. https://doi.org/10.1021/es202518n.

Wales, A.D. and Davies, R.H. (2015). Co-Selection of resistance to antibiotics, biocides and heavy metals, and its relevance to foodborne pathogens. *Antibiotics* 4(4) 567-604. https://doi.org/10.3390/antibiotics4040567.

Wang, Y.-X., You, L., Zeng, Q., Sun, Y., Huang, Y.-H., Wang, C., Wang, P., Cao, W.-C., Yang, P., Li, Y.-F. and Lu, W.-Q. (2015). Phthalate exposure and human semen quality: results from an infertility clinic in China. *Environmental Research* 142, 1-9. https://doi.org/10.1016/J.ENVRES.2015.06.010.

Women in Europe for a Common Future (2016). *Women and Chemicals: The Impact of Hazardous Chemicals on Women. A Thought Starter Based on an Experts' Workshop*. http://www.wecf.eu/download/2016/March/WomenAndChemicals_PublicationIWD2016.pdf.

Wood, M. (2017). JRC study of chemical accidents in the media during 2016-2017, for OECD. In *Disaster Risk Management Knowledge Center: Pooling Knowledge and Networks in Disaster Risk Management: Newsletter #11*. Wakehnhut, F. (ed.). European Commission. 10. https://drmkc.jrc.ec.europa.eu/DesktopModules/CritechDocumentItems/API/CritechDocumentItems/Download?contentItemId=8778&forceDownload=true

World Health Organization (2009). *Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks*. http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_Front.pdf.

World Heatlth Organization (2011). *An Overview of the Evidence on Environmental and Occupational Determinants of Cancer.* http://www.who.int/phe/news/events/international_conference/Background_science.pdf.

World Health Organization (2016). *The Public Health Impact of Chemicals: Knowns and Unknowns*. http://apps.who.int/iris/bitstream/handle/10665/206553/WHO_FWC_PHE_EPE_16.01_eng.pdf?sequence=1.

World Health Organization (2017). *Chemical Mixtures in Source Water and Drinking-Water*. http://apps.who.int/iris/bitstream/handle/10665/255543/9789241512374-eng.pdf;jsessionid=945450215FE5D872A33483300F7FD600?sequence=1.

World Health Organization (2018a). *The Public Health Impact of Chemicals: Knowns and Unknowns - Data Addendum for 2016*. http://www.who.int/ipcs/publications/chemicals-public-health-impact/en/.

World Health Organization (2018b). *World Health Statistics 2018: Monitoring Health for the SDGs, Sustainable Development Goals*. http://apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf?ua=1.

World Health Organization (2018c). Cancer: key facts, 12 September. http://www.who.int/news-room/fact-sheets/detail/cancer. Accessed 16 February 2019.

World Health Organization (2018d). Lead poisoning and health, 28 August. http://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health. Accessed 16 February 2019.

World Health Organization (2019). Ten threats to global health in 2019. https://www.who.int/emergencies/ten-threats-to-global-health-in-2019. Accessed 16 February 2019.

World Meteorological Organization (2018). *Scientific Assessment of Ozone Depletion: 2018*. Global Ozone Research and Monitoring Project–Report No. 58. https://ozone.unep.org/sites/default/files/Assessment_Panel/SAP-2018-Assessment-report.pdf.

Zhao, L., Quian, Y., Hu, A.-M., Jian, R, Li, M. and Wang, X. (2018). An analysis of hazardous chemical accidents in China between 2006 and 2017. *Sustainability* 10(8), 2935. https://doi.org/10.3390/su10082935.

Zock, J.-P., Vizcaya, D. and Le Moual, N. (2010). Update on asthma and cleaners. *Current Opinion in Allergy and Clinical Immunology* 10(2), 114-120. https://doi.org/10.1097/ACI.0b013e32833733fe.

Zota, A.R. and Shamasunder, B. (2017). The environmental injustice of beauty: framing chemical exposures from beauty products as a health disparities concern. *American Journal of Obstetrics and Gynecology* 217(4), 418.e1-418.e6. http://doi.org/10.1016/j.ajog.2017.07.020.

## Chapter 8

Amec Foster Wheeler [now the Wood Group], Brunel University, Economics for the Environment Consultancy and Peter Fisk Associates (2017). *Study on the Cumulative Health and Environmental Benefits of Chemical Legislation*. https://publications.europa.eu/en/publication-detail/-/publication/b43d720c-9db0-11e7-b92d-01aa75ed71a1/language-en. .

Amec Foster Wheeler [now the Wood Group], Trinomics and Technopolis (2017). *Study Supporting the Fitness Check on the Most Relevant Chemicals Legislation ("Fitness Check+")*. Brussels: European Commission. https://doi.org/10.2779/540096.

Attina, T.M. and Trasande, L. (2013). Economic costs of childhood lead exposure in low- and middle-income countries. *Environmental Health Perspectives*. 121(9), 1097-1102. https://dx.doi.org/10.1289/ehp.1206424.

Attina, T.M., Hauser, R., Sathyanarayana, S., Hunt, P.A., Bourguignon, J.-P., Myers, J.P., DiGangi, J., Zoeller, R.T. and Trasande, L. (2016). Exposure to endocrine-disrupting chemicals in the USA: a population-based disease burden and cost analysis. *The Lancet Diabetes & Endocrinology* 4(12), 996-1003. https://doi.org/10.1016/s2213-8587(16)30275-3.

Bellanger, M., Pichery, C., Aerts, D., Berglund, M., Castaño, A., Čejchanová, M., Crettaz, P., Davidson, F., Esteban, M., Fischer, M.E., Gurzau, A.E., Halzlova, K., Katsonouri, A., Knudsen, L.E., Kolossa-Gehring, M., Koppen, G., Ligocka, D., Miklavčič, A., Reis, M.F., Rudnai, P., Tratnik, J.S., Weihe, P., Budtz-Jørgensen, E. and Grandjean, P. (2013). Economic benefits of methylmercury exposure control in Europe: monetary value of neurotoxicity prevention. *Environmental Health*. 12(1), 3. https://doi.org/10.1186/1476-069X-12-3.

Bellanger, M., Demeneix, B., Grandjean, P., Zoeller, R.T. and Trasande, L. (2015). Neurobehavioral deficits, diseases, and associated costs of exposure to endocrine-disrupting chemicals in the European Union. *Journal of Clinical Endocrinology & Metabolism*. 100(4), 1256-1266. https://doi.org/10.1210/jc.2014-4323.

Bond, G.G. and Dietrich, D.R. (2017). Human cost burden of exposure to endocrine disrupting chemicals. a critical review. *Archives of Toxicology*. 91(8), 2745-2762. https://doi.org/10.1007/s00204-017-1985-y.

Cao, Y., Li, L., Shen, K. and Liu, J. (2019). Disease burden attributable to endocrine-disrupting chemicals exposure in china: a case study of phthalates. *Science of The Total Environment* 662, 615-621. https://doi.org/10.1016/j.scitotenv.2019.01.255.

Chaplin-Kramer, B. and Green, J. (n.d.). *Biodiversity and Ecosystem Services in Environmental Profit & Loss Accounts*. Working Paper. Cambridge: University of Cambridge Institute for Sustainable Leadership. https://www.cisl.cam.ac.uk/resources/publication-pdfs/BESinEPLWorkingPaper.pdf.

Chiu, W.A. (2017). *Chemical Risk Assessment and Translation to Socio-Economic Assessments*. Paris: Organisation for Economic Co-operation and Development. http://dx.doi.org/10.1787/a930054b-en.

Das, P. and Horton, R. (2018). Pollution, health, and the planet: time for decisive action. *The Lancet*. 391(10119), 407-408. https://doi.org/10.1016/S0140-6736(17)32588-6.

Dudley, S.E. (2017). *Retrospective Evaluation of Chemical Regulations*. Paris: Organisation for Economic Co-operation and Development. https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/WKP(2017)5&docLanguage=En.

European Chemicals Agency (2016). *Cost and Benefit Assessments in the REACH Restriction Dossiers*. https://echa.europa.eu/documents/10162/13630/cost_benefit_assessment_en.pdf.

European Chemicals Agency (2017). *Socio-Economic Impacts of REACH Authorisations – A Meta-Analysis of the First 100 Applications for Authorisation*. https://doi.org/10.2823/794664.

European Chemicals Agency (n.d.). Willingness to pay to avoid certain health impacts. https://echa.europa.eu/support/socio-economic-analysis-in-reach/willingness-to-pay-to-avoid-certain-health-impacts. Accessed 16 August 2018.

Gabbert, S. (2018). *Economic Assessment and Valuations of Environmental and Health Impacts Caused by Perfluorooctanoic Acid (PFOA) and Its Salts*. Paris: Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/content/paper/f5250745-en.

GBD 2016 DALYs and HALE Collaborators (2017). Global, regional, and national disability-adjusted life-years (DALYs) for 333 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*. 390(10100), 1260-1344. https://doi.org/10.1016/S0140-6736(17)32130-X.

Government of Canada (2018). Prohibition of asbestos and products containing asbestos regulations: SOR/2018-196. *Canada Gazette, Part II* 152(21), 3371-3532. http://gazette.gc.ca/rp-pr/p2/2018/2018-10-17/html/sor-dors196-eng.html.

Grandjean, P. and Bellanger, M. (2017). Calculation of the disease burden associated with environmental chemical exposures: application of toxicological information in health economic estimation. *Environmental Health* 16(123), 1-13. https://doi.org/10.1186/s12940-017-0340-3.

Harremoes, P., Gee, D., MacGavin, M., Stirling, A., Keys, J., Wynne, B. and Vaz, S.G. (eds.) (2001) *Late Lessons from Early Warnings: The Precautionary Principle 1896-2000*. Copenhagen: European Environment Agency. https://www.eea.europa.eu/publications/environmental_issue_report_2001_22.

Hauser, R., Skakkebaek, N.E., Hass, U., Toppari, J., Juul, A., Andersson, A.M., Kortenkamp, A., Heindel, J.J. and Trasande, L. (2015). Male reproductive disorders, diseases, and costs of exposure to endocrine-disrupting chemicals in the European Union. *The Journal of Clinical Endocrinology & Metabolism* 100(4), 1267-1277. https://doi.org/10.1210/jc.2014-4325.

Helbling, T. (2017). Externalities: prices do not capture all costs - back to basics, 29 July. *International Monetary Fund*. http://www.imf.org/external/pubs/ft/fandd/basics/external.htm. Accessed 19 July 2018.

Holland, M. (2018). *Socio-Economic Assessment of Phthalates*. Paris: Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/content/paper/a38a0e34-en.

Hunt, A. and Dale, N. (2018a). *Economic Valuation in Formaldehyde Regulation*. Paris: Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/content/paper/c0f8b8e5-en.

Hunt, A. and Dale, N. (2018b). *Economic Valuation in 1-Methyl-2-Pyrrolidone (NMP) Regulation*. Paris: Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/content/paper/ef67fa08-en.

Hunt, P.A., Sathyanarayana, S., Fowler, P.A. and Trasande, L. (2016). Female reproductive disorders, diseases, and costs of exposure to endocrine disrupting chemicals in the European Union. *The Journal of Clinical Endocrinology & Metabolism*. 101(4), 1562-1570. https://doi.org/10.1210/jc.2015-2873.

Landrigan, P.J., Fuller, R., Acosta, N.J.R., Adeyi, O., Arnold, R., Basu, N.N., Baldé, A.B., Bertollini, R., Bose-O'Reilly, S., Boufford, J.I., Breysse, P.N., Chiles, T., Mahidol, C., Coll-Seck, A.M., Cropper, M.L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. V, McTeer, M.A., Murray, C.J.L., Ndahimananjara, J.D., Perera, F., Potočnik, J., Preker, A.S., Ramesh, J., Rockström, J., Salinas, C., Samson, L.D., Sandilya, K., Sly, P.D., Smith, K.R., Steiner, A., Stewart, R.B., Suk, W.A., van Schayck, O.C.P., Yadama, G.N., Yumkella, K. and Zhong, M. (2018). The lancet commission on pollution and health. *The Lancet*. 391(10119), 462-512. https://doi.org/10.1016/S0140-6736(17)32345-0.

Lanphear, B.P., Rauch, S., Auinger, P., Allen, R.W. and Hornung, R.W. (2018). Low-level lead exposure and mortality in US adults: a population-based cohort study. *The Lancet Public Health*. 3(4), e177-e184. https://doi.org/10.1016/S2468-2667(18)30025-2.

Legler, J., Fletcher, T., Govarts, E., Porta, M., Blumberg, B., Heindel, J.J. and Trasande, L. (2015). Obesity, diabetes, and associated costs of exposure to endocrine-disrupting chemicals in the European Union. *The Journal of Clinical Endocrinology & Metabolism*. 100(4), 1278-1288. https://doi.org/10.1210/jc.2014-4326.

Makino, R. (2016). Stock market responses to chemical accidents in Japan: an event study. *Journal of Loss Prevention in the Process Industries*. 44, 453-458. https://doi.org/10.1016/j.jlp.2016.10.019.

Malits, J., Blustein, J., Trasande, L. and Attina, T.M. (2018). Perfluorooctanoic acid and low birth weight: estimates of US attributable burden and economic costs from 2003 through 2014. *International Journal of Hygiene and Environmental Health*. 221(2), 269-275. https://doi.org/10.1016/j.ijheh.2017.11.004.

Marques, A., Verones, F., Kok, M.T., Huijbregts, M.A. and Pereira, H.M. (2017). How to quantify biodiversity footprints of consumption? A review of multi-regional input–output analysis and life cycle assessment. *Current Opinion in Environmental Sustainability*. 29, 75-81. https://doi.org/10.1016/J.COSUST.2018.01.005.

Navrud, S. (2017). *Possibilities and Challenges in Transfer and Generalization of Monetary Estimates for Environmental and Health Benefits of Regulating Chemicals*. Paris: Organisation for Economic Co-operation and Development. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/WKP(2017)6&docLanguage=En.

Nordic Council of Ministers (2015). *The Cost of Inaction: A Socioeconomic Analysis of Costs Linked to Effects of Endocrine Disrupting Substances on Male Reproductive Health*. https://doi.org/10.13140/2.1.1107.9360.

Organisation for Economic Co-operation and Development (2010). *The Value of Statistical Life: A Meta-Analysis.* http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WPNEP(2010)9/FINAL&doclanguage=en.

Organisation for Economic Co-operation and Development (2018). The costs and benefits of regulating chemicals. http://www.oecd.org/chemicalsafety/risk-management/sacame.htm. Accessed 1 January 2019.

Prüss-Ustün, A., Wolf, J., Corvalán, C., Bos, R. and Neira, M. (2016). *Preventing Disease through Healthy Environments: A Global Assessment of the Burden of Disease from Environmental Risks*. Geneva: World Health Organization. http://apps.who.int/iris/bitstream/handle/10665/204585/9789241565196_eng.pdf?sequence=1.

Rijk, I., van Duursen, M. and van den Berg, M. (2016). *Health Costs That May Be Associated with Endocrine Disrupting Chemicals: An Inventory, Evaluation and Way Forward to Assess the Potential Socio-Economic Impact of EDC-Associated Health Effects in the EU*. Utrecht: Institute for Risk Assessment Sciences, Universiteit Utrecht. https://www.uu.nl/sites/default/files/rijk_et_al_2016_-_report_iras_-_health_cost_associated_with_edcs_3.pdf.

Shapira, R. and Zingales, L. (2017). *Is Pollution Value-Maximizing? The DuPont Case*. Chicago, IL: Stigler Center for the Study of the Economy and State University of Chicago Booth School of Business. https://research.chicagobooth.edu/-/media/research/stigler/pdfs/workingpapers/13ispollutionvaluemaximizingsep2017.pdf?la=en&hash=1D5A23E77971DDA8BE5223911DE96AF2429D2C06.

Sørensen, M.M., Feng, M.C., Von Bahr, J., Sletten, T.M., Kiiski, J. and Krarup, S. (2017). *Valuation Literature on Chemicals: A Description of an Inventory of Valuation Literature on Chemicals*. Copenhagen: Nordic Council of Ministers. http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A1067125&dswid=-4137.

Stern, N. (2007). *The Economics of Climate Change: Stern Review*. Cambridge: Cambridge University Press. http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf.

The Actuary (2002). Asbestos claims in Europe. http://www.theactuary.com/archive/old-articles/part-3/asbestos-claims-in-europe/. Accessed 10 July 2018.

The Economics of Ecosystems and Biodiversity (n.d.). The economics of ecosystems and biodiversity (TEEB). http://www.teebweb.org/. Accessed 16 August 2018.

Trasande, L., Zoeller, R.T., Hass, U., Kortenkamp, A., Grandjean, P., Myers, J.P., DiGangi, J., Bellanger, M., Hauser, R., Legler, J., Skakkebaek, N.E. and Heindel, J.J. (2015). Estimating burden and disease costs of exposure to endocrine-disrupting chemicals in the European Union. *The Journal of Clinical Endocrinology & Metabolism*. 100(4), 1245-1255. https://doi.org/10.1210/jc.2014-4324.

Trasande, L., DiGangi, J., Evers, D.C., Petrlik, J., Buck, D.G., Šamánek, J., Beeler, B., Turnquist, M.A. and Regan, K. (2016a). Economic implications of mercury exposure in the context of the global mercury treaty: hair mercury levels and estimated lost economic productivity in selected developing countries. *Journal of Environmental Management*. 183, 229-235. https://doi.org/10.1016/j.jenvman.2016.08.058.

Trasande, L., Zoeller, R.T., Hass, U., Kortenkamp, A., Grandjean, P., Myers, J.P., DiGangi, J., Hunt, P.M., Rudel, R., Sathyanarayana, S., Bellanger, M., Hauser, R., Legler, J., Skakkebaek, N.E. and Heindel, J.J. (2016b). Burden of disease and costs of exposure to endocrine disrupting chemicals in the European Union: an updated analysis. *Andrology*. 4(4), 565-572. https://doi.org/10.1111/andr.12178.

United Nations Environment Programme (2013). *Costs of Inaction on the Sound Management of Chemicals*.http://wedocs.unep.org/bitstream/handle/20.500.11822/8412/-Costs of inaction on the sound management of chemicals-2013Report_Cost_of_Inaction_Feb2013.pdf?sequence=3&isAllowed=y.

United Nations Environment Programme (2016). *Global Review of Mercury Monitoring Networks*. http://www.mercuryconvention.org/Portals/11/documents/2016 call for submissions/UNEP - Global Review of Mercury Monitoring Networks_Final.pdf.

United Nations Environment Programme (n.d.). Global mercury partnership. http://web.unep.org/globalmercurypartnership/#parentHorizontalTab2. Accessed 7 September 2018.

United States Environmental Protection Agency (1997). *Benefits and Costs of the Clean Air Act, 1970-1990*. https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act-1970-1990-retrospective-study.

United States Environmental Protection Agency (2015). *Updating Ozone Calculations and Emission Profiles for Use in the Atmospheric and Health Effects Framework Model*. https://www.epa.gov/ozone-layer-protection/updating-ozone-calculations-and-emissions-profiles-use-atmospheric-and-health.

United States Environmental Protection Agency (2018). International actions for reducing mercury emissions and use, 16 July. https://www.epa.gov/international-cooperation/international-actions-reducing-mercury-emissions-and-use. Accessed 7 September 2018.

Wilting, H.C., Schipper, A.M., Bakkenes, M., Meijer, J.R. and Huijbregts, M.A.J. (2017). Quantifying biodiversity losses due to human consumption: a global-scale footprint analysis. *Environmental Science & Technology* 51(6), 3298-3306. https://doi.org/10.1021/acs.est.6b05296.

World Bank (1993). *World Development Report 1993: Investing in Health*. New York: Oxford University Press. https://openknowledge.worldbank.org/bitstream/handle/10986/5976/9780195208900_fm.pdf.

# II. Where do we stand in achieving the 2020 goal – assessing overall progress and gaps



Closing plenary of the World Summit on Sustainable Development, 4 September 2002, Johannesburg, South Africa

## About Part II

Part II provides insights into progress made towards the 2020 goal to "achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment […]". Chapter 1 introduces existing international agreements and frameworks on chemicals and waste. It covers multilateral legally binding treaties, voluntary international instruments, SAICM and relevant Sustainable Development Goals (SDGs) and targets under the 2030 Agenda for Sustainable Development. Chapter 2 features an overview of reporting and indicator schemes under these agreements. Chapter 3 documents progress in achieving the sound management of chemicals and waste, as well as implementation gaps.

Responding to the mandate received from the United Nations Environment Assembly (UNEA), Part II also addresses emerging policy issues identified by the International Conference on Chemicals Management (ICCM) and issues where emerging evidence indicates a risk to human health and the environment. The final chapter of Part II concludes with a discussion of insights and lessons learned in making progress towards achieving the 2020 goal.

## Contents

1/ International agreements and frameworks on chemicals and waste 220

2/ Reporting schemes and indicators under international agreements and frameworks 228

3/ Achieving the 2020 goal: what do we know? 241

4/ Emerging policy issues and other issues of concern 291

5/ Other issues where emerging evidence indicates a risk 320

6/ Overall progress towards the 2020 goal: what have we learned? 330

Annex: Other issues where emerging evidence indicates a risk 335

References 347

# 1/ International agreements and frameworks on chemicals and waste

## Chapter Highlights

Governments have taken action on chemicals and waste at the national and international level for decades, leading, among others, to adoption of a number of multilateral legally binding treaties.

The multilateral treaties cover different chemicals and different stages of the life cycle and have different goals. They also vary in the number of Parties.

The Strategic Approach to International Chemicals Management (SAICM) is a global voluntary, multi-sectoral, multi-stakeholder policy framework taking a comprehensive life cycle approach.

The International Code of Conduct on Pesticide Management and the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) are non-binding global policy instruments addressing some core capacities for chemicals management.

The 2030 Agenda for Sustainable Development includes a number of Sustainable Development Goals (SDGs) and targets that are directly or indirectly relevant for chemicals and waste.

The Introduction to the GCO-II gives an overview of milestones in international chemicals and waste management, from early action at the beginning of the 20th century to the 2030 Agenda for Sustainable Development. This chapter describes international agreements and frameworks that are relevant to assessing progress towards the 2020 goal in more detail, namely multilateral treaties on chemicals and waste, voluntary international instruments (including SAICM) and the 2030 Agenda. It provides the structure for Chapter 2, which discusses the reporting mechanisms for chemicals and waste.

## 1.1 Multilateral treaties on chemicals and waste

Since 1987 a number of multilateral treaties have established goals and targets for different aspects of the sound management of chemicals and waste. Complementing soft law approaches such as Agenda 21 (the non-binding action plan adopted at the United Nations Conference on Environment and Development in 1992), the Montreal Protocol and the Basel, Rotterdam, Stockholm and Minamata Conventions (Table 1.1) have created an international chemicals and waste control framework covering the management and elimination of specific chemicals and wastes across all stages of their life cycle. These multilateral instruments have served to identify and address chemicals of the highest concern at the international level.

Table 1.1 gives an overview of the multilateral legally binding agreements related to the sound management of chemicals and waste, including the number of chemical substances addressed (not including isomers of listed substances). Under several agreements (such as the Montreal, Rotterdam and Stockholm treaties) there is an opportunity to add further substances.

**Table 1.1** **Multilateral agreements related to the sound management of chemicals and waste**

| Agreement | Adoption and entry into force | Goals | Number of chemical substances addressed | Number of Parties as of 14 January 2019 |
|---|---|---|---|---|
| Montreal Protocol on Substances that Deplete the Ozone Layer | › Adopted at the Conference of Plenipotentiaries on the Protocol on Chlorofluorocarbons to the Vienna Convention for the Protection of the Ozone Layer in Montreal in 1987<br>› Entered into force in 1989 | › Protect human health and the environment against adverse effects resulting, or likely to result, from human activities which modify or are likely to modify the ozone layer;<br>› Protect the ozone layer by taking precautionary measures to control equitably the total global production and consumption of substances that deplete it, with the ultimate objective of their elimination on the basis of scientific knowledge, technical and economic considerations, and the developmental needs of developing countries.<br>(United Nations [UN] 2018) | 144 | 197 |
| Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal | › Adopted at the Conference of Plenipotentiaries in Basel in 1989<br>› Entered into force in 1992 | › Effective implementation of Parties' obligations with respect to transboundary movements of hazardous and other wastes;<br>› Strengthening the environmentally sound management of hazardous and other wastes;<br>› Promoting the implementation of environmentally sound management of hazardous and other wastes as an essential contribution to the attainment of sustainable livelihood, the 2000 Millennium Development Goals, and the protection of human health and the environment.<br>(Secretariat of the Basel Convention 2011a; Secretariat of the Basel Convention 2011b) | 124 groups of wastes, according to Annex I, II and VIII List A, and wastes falling under the criteria of the list of hazardous characteristics in Annex III | 187 |

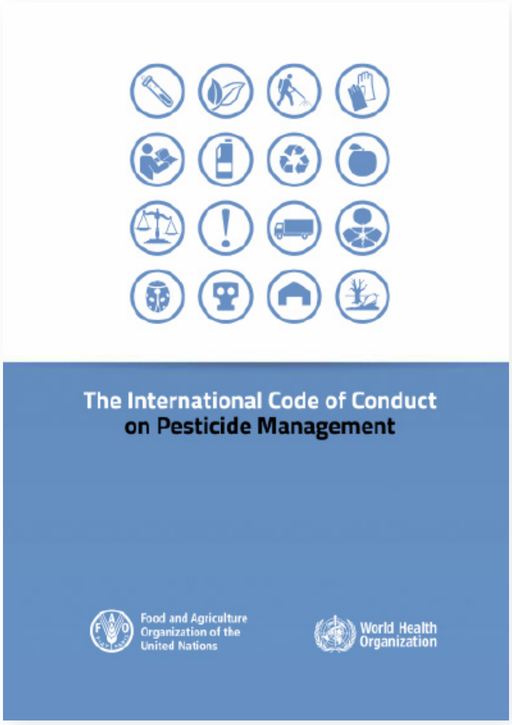
| Agreement | Adoption and entry into force | Goals | Number of chemical substances addressed | Number of Parties as of 14 January 2019 |
|---|---|---|---|---|
| ILO Chemicals Convention C170<br>International Labour Organization | › Adopted at the 77th Session of the International Labour Conference in Geneva in 1990<br>› Entered into force in 1993 | › Reduce the incidence of chemically induced illnesses and injuries at work by ensuring that all chemicals are evaluated to determine their hazards;<br>› Provide employers with a mechanism to obtain information from suppliers about the chemicals used at work;<br>› Provide workers with information about the chemicals at their workplaces, and about appropriate preventive measures so that they can effectively participate in protective programmes;<br>› Establish principles for such programmes to ensure that chemicals are used safely.<br>(ILO 2017a) | Not applicable | 21 |
| Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction | › Adopted at the 635th plenary meeting of the Conference on Disarmament in Geneva in 1992<br>› Entered into force in 1997 | › Achieve effective progress towards general and complete disarmament under strict and effective international control, including the prohibition and elimination of all types of weapons of mass destruction;<br>› Exclude completely the possibility of the use of chemical weapons, including prohibition of the use of herbicides as a method of warfare;<br>› Promote free trade in chemicals, as well as international cooperation and exchange of scientific and technical information in the field of chemical activities for purposes not prohibited under the Convention;<br>› Completely and effectively prohibit the development, production, acquisition, stockpiling, retention, transfer and use of chemical weapons, and their destruction<br>(Organisation for the Prohibition of Chemical Weapons 2019) | 15 toxic chemicals and 28 precursors | 193 |
| ILO Convention concerning the Prevention of Major Industrial Accidents C174<br>International Labour Organization | › Adopted at the 80th Session of the International Labour Conference in Geneva in 1993<br>› Entered into force in 1997 | Having regard to the need to ensure that all appropriate measures are taken to:<br>› Prevent major accidents;<br>› Minimize the risks of major accidents;<br>› Minimize the effects of major accidents.<br>(ILO 2017b) | Not applicable | 18 |

| Agreement | Adoption and entry into force | Goals | Number of chemical substances addressed | Number of Parties as of 14 January 2019 |
|---|---|---|---|---|
| Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade<br>ROTTERDAM CONVENTION | › Adopted at the Conference of Plenipotentiaries on the Convention in Rotterdam in 1998<br>› Entered into force in 2004 | › Promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals, in order to protect human health and the environment from potential harm and to contribute to their environmentally sound use, by facilitating information exchange about their characteristics, by providing for a national decision-making process on their import and export and by disseminating these decisions to Parties.<br>(Secretariat of the Rotterdam Convention 2010) | 50 substances and mercury compounds | 161 |
| Stockholm Convention on Persistent Organic Pollutants<br>STOCKHOLM CONVENTION | › Adopted at the Conference of Plenipotentiaries on the Stockholm Convention on Persistent Organic Pollutants in Stockholm in 2001<br>› Entered into force in 2004 | › Protect human health and the environment from Persistent Organic Pollutants (POPs);<br>› Eliminate or restrict the production, use, import and export of listed POPs, and require measures to be taken with respect to waste and unintentional releases of POPs.<br>(Secretariat of the Stockholm Convention 2008) | 28 POPs and mentioned salts | 182 |
| WHO International Health Regulations (IHR) (2005)<br>WHO | › Adopted by the 58th World Health Assembly in Geneva in 2005<br>› Entered into force in 2007 | › Prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade (Article 2).<br>(World Health Organization [WHO] 2016) | Not applicable | 196 |
| Minamata Convention on Mercury<br>MINAMATA CONVENTION ON MERCURY | › Adopted on the occasion of the Conference of Plenipotentiaries on the Minamata Convention on Mercury in 2013<br>› Entered into force in 2017 | › Protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.<br><br>Commitments by Parties include:<br>› Ban new mercury mines and phase out existing ones;<br>› Phase out and phase down mercury use in a number of products and processes;<br>› Establish control measures for emissions to air and releases to land and water;<br>› Environmentally sound interim storage of mercury, and its disposal once it becomes waste.<br>(United Nations Environment Programme [UNEP] 2018) | Mercury and mercury compounds | 101 |

## 1.2 Voluntary international instruments

In addition to legally binding treaties, several voluntary international instruments adopted by the governing bodies of international organizations address a wide range of chemicals and issues. Prominent examples include the International Code of Conduct on Pesticide Management, the GHS and SAICM.

### The International Code of Conduct on Pesticide Management




The International Code of Conduct on Pesticide Management is the pesticide management framework for all public and private entities engaged in (or associated with) the production, regulation and management of pesticides. It was approved by the Conference of the Food and Agriculture Organization of the United Nations (FAO) in June 2013 as the successor to the International Code of Conduct on the Distribution and Use of Pesticides (adopted in 1985 and revised in 2002). The new International Code of Conduct serves as a point of reference for sound pesticide life cycle management practices, particularly with respect to government authorities and the pesticide industry. The voluntary standards it sets out are especially relevant where there is inadequate or no national legislation concerned with pesticide regulation. Among other objectives, the new International Code of Conduct seeks to promote practices, including integrated pest management, that minimize the potential health and environmental risks associated with pesticides while ensuring their effective use (FAO 2018).

### The Globally Harmonized System of Classification and Labelling of Chemicals

The GHS is an internationally agreed-upon standard managed by the United Nations. It was first adopted in 2002 and subsequently revised several times (seventh revision in 2017). Against the background of the extensive global trade in chemicals, as well as the significant differences in labels and safety data sheets for the same product across countries, it was recognized that an internationally harmonized approach to classification and labelling of chemicals would provide the foundation for national programmes to ensure their safe use, transport and disposal. The GHS thus aims to provide countries with consistent and appropriate information on the chemicals they either import or produce.

An important core element of the GHS consists of standardized chemical hazard criteria to support government and industry in undertaking chemical hazard classifications. The GHS also features universal warning pictograms and a harmonized approach to the preparation of safety data sheets which provide users of dangerous goods with extensive information. The Johannesburg Plan of Implementation (JPOI), adopted by the World Summit on Sustainable Development in 2002, encouraged countries to implement the GHS as soon as possible, with a view to the system being fully operational by 2008.

## 1.3 The Strategic Approach to International Chemicals Management (SAICM)

Paragraph 23(b) of the 2002 JPOI called for the development of a "strategic approach to international chemicals management based on the [2000] Bahia Declaration and Priorities for Action beyond 2000 of the Intergovernmental Forum on Chemical Safety by 2005". In 2006 the Strategic Approach to International Chemicals Management (SAICM) was adopted by the first International Conference on Chemicals Management (ICCM1) held in Dubai, United Arab Emirates. SAICM was developed by a multi-stakeholder and multi-sectoral Preparatory Committee. Its overall objective, as described in paragraph 13 of its Overarching Policy Strategy (OPS), is "to achieve the sound management of chemicals throughout their life cycle so that by the year 2020, chemicals are produced and used in ways that minimize significant adverse impacts on the environment and human health" (Secretariat of the Strategic Approach to International Chemicals Management [SAICM Secretariat], UNEP and WHO 2006).

SAICM differs from other chemical and waste agreements on several key points: it is a voluntary non-binding policy framework; it supports a comprehensive life cycle approach for all hazardous chemicals; and it allows for active participation by non-governmental stakeholders (Persson, Persson and Sam 2014). SAICM has three main elements, two of which were adopted at the International Conference in Dubai (Box 1.1).

The Dubai Declaration states that, together with the OPS, it constitutes a firm commitment to SAICM and its implementation. These two documents provide the rationale for the creation of SAICM and its overarching principles and goals (Persson, Persson and Sam 2014). The Dubai

**Box 1.1 The elements of the Strategic Approach to International Chemicals Management (SAICM)**

*The Dubai Declaration on International Chemicals Management*

The Dubai Declaration, adopted at the 2006 International Conference, expresses high-level political support "for promoting the sound management of chemicals and wastes throughout their life-cycle, in accordance with Agenda 21 and paragraph 23 of the JPOI". The Declaration explicitly states that significant, but insufficient, progress had been made in the implementation of Chapter 19 of Agenda 21 and other relevant international instruments concerning chemicals and waste.

*The Overarching Policy Strategy (OPS)*

The OPS, also adopted at the Conference, includes sections on the statement of needs, objectives, financial considerations, principles and approaches, implementation, and taking stock of progress.

The five key thematic objectives in the OPS are:

- risk reduction;
- knowledge and information;
- governance;
- capacity building and technical cooperation; and
- illegal international traffic in chemicals.

These thematic objectives are further divided into 46 specific objectives.

*The Global Plan of Action (GPA)*

The GPA lists possible work areas and 299 associated activities, as well as actors, targets/timeframes, indicators of progress, and implementation aspects. The GPA is a non-negotiated text and therefore has a different status than the Dubai Declaration and the OPS described above. However, the Conference recommended its use and further development.

Declaration also acknowledges that SAICM is a new voluntary initiative in the field of chemicals management, and that it is not a legally binding instrument (SAICM Secretariat, UNEP and WHO 2006).

## 1.4 Chemicals and waste in the 2030 Agenda for Sustainable Development

A number of targets in the 2030 Agenda for Sustainable Development (which was adopted by all United Nations Member States in 2015) are directly or indirectly relevant to the sound management of chemicals and waste. Several targets, including 12.4, 3.9 and 6.3, contain direct references to chemicals. Some of the Sustainable Development Goals (SDGs) also provide specific development objectives linked to chemicals management. In addition, SDGs and targets that seek to strengthen an enabling environment to advance sustainable development are relevant to chemicals management.

### SDG targets focusing on chemicals and waste management

Target 12.4 is directly linked to (and encompasses) successful implementation of the chemicals and waste multilateral environmental agreements (MEAs), the SAICM and other relevant policies and actions. Equally important, Target 3.9 focuses on the ultimate impact of enhanced sound management of chemicals and waste in terms of human health. Target 6.3 sheds light on media-specific dimensions, highlighting the need for reduced pollution to maintain water quality.

- SDG 3 on Good Health and Well-Being, Target 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
- SDG 6 on Clean Water and Sanitation, Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally.
- SDG 12 on Responsible Consumption and Production, Target 12.4: By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

Also relevant to the sound management of chemicals and waste are SDG targets concerning environmental and social objectives related to chemicals and waste management action. These include the following:

- SDG 8 on Decent Work and Economic Growth, Target 8.8 on the protection of labour rights and promotion of safe working environments.
- SDG 12 on Sustainable Consumption and Production, Target 12.5 on the reduction of waste generation.
- SDG 14 on Life Below Water, Target 14.1 on the reduction of marine pollution.
- SDG 15 on Life on land, Target 15.5 on the protection of biodiversity and natural habitats.

## SDG targets fostering economic development and strengthening the enabling environment

The 2030 Agenda includes a number of SDGs with specific development objectives. Given the indivisible nature of the 2030 Agenda, sound management of chemicals and waste is an important consideration for achieving the development-related SDGs and targets. Like all SDGs and targets, they require consideration and careful balancing of the economic, social and environmental dimensions of sustainable development to ensure that progress on certain indicators does not come at the expense of others. Relevant economic sectors and related SDGs include the following:

- SDG 8 on Decent Work and Economic Growth, Target 8.8 on the protection of labour rights and promotion of safe working environments.
- SDG 2 on Zero Hunger, Target 2.1 on access to safe, nutritious and sufficient food.
- SDG 7 on Affordable and Clean Energy, Target 7.a on clean energy.
- SDG 11 on Sustainable Cities and Communities, Target 11.1 on safe and affordable housing.

A number of SDGs and targets seek to strengthen an enabling environment to advance sustainable development. Putting in place certain enabling conditions can help facilitate the sound management of chemicals and waste and maximize the benefits of chemistry. Relevant enabling sectors and related SDGs include the following:

- SDG 4 on Quality Education, Target 4.7 on education for sustainable development.
- SDG 16 on Peace, Justice and Strong Institutions, Target 16.10 on public access to information.
- SDG 17 on Partnerships for the Goals, Target 17.3 on mobilizing financial resources.

# 2/ Reporting schemes and indicators under international agreements and frameworks

## Chapter Highlights

National reporting, and the use of indicators, are important mechanisms for monitoring and tracking both the implementation and effectiveness of international agreements.

International chemicals and waste agreements have individual reporting processes and indicators, each with its own particular features. There is also a global indicator framework for the Agenda 2030 SDGs and targets.

Participating organizations of the Inter-Organization Programme for the Sound Management of Chemicals (IOMC) collect information about progress on selected indicators.

Reporting rates vary across international agreements. High reporting rates have been achieved for the WHO International Health Regulations (2005); reporting rates under the Basel and Stockholm Conventions have not been optimal and show decreasing trends.

SAICM has the most comprehensive framework for monitoring progress, but reporting rates are not satisfactory.

Building upon the structure provided in Chapter 1, this chapter examines existing reporting and indicator schemes that have been developed under relevant international agreements and frameworks. They include the mechanisms developed under multilateral treaties, voluntary international instruments, SAICM and the 2030 Agenda for Sustainable Development. In addition, the IOMC tracks progress regarding selected activities. The effectiveness and coherence of these reporting schemes and indicators is examined to the extent possible, with findings indicating a fragmented landscape.

## 2.1 Reporting schemes and indicators under multilateral treaties on chemicals and waste

### National reporting: tracking progress, identifying challenges

All the legally binding multilateral agreements related to sound management of chemicals and waste discussed in Part II, Ch. 1 have a reporting obligation, with the exception of the Rotterdam Convention on Prior Informed Consent. The common aim is to measure progress in regard to technical obligations, implementation of legislation, establishment of institutions, and collection of data on the issues addressed by each agreement. The analysis and discussion of national reports - including of their availability as well as their content - are important in order to help understand implementation challenges and opportunities. They are also important for the development of tools to make information exchange and mutual learning effective. The Secretariat of each agreement can play a critical role in identifying barriers to implementation.

The reporting rates, results, content and format of reporting vary with each agreement, although there are a number of similarities. Frequency of reporting is annual in most cases; for the Stockholm Convention it is every four years. Reporting is carried out using electronic formats, although for the WHO International Health Regulations (IHR) (2005) paper copies can be submitted. Questions to be addressed through reporting can relate to activities and/or the outcomes of activities, as well as to information about implementation challenges encountered. In the case of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, the Stockholm Convention on POPs, and the Minamata Convention on Mercury, reporting addresses activities and outcomes; in the case of the Montreal Protocol on Substances that Deplete the Ozone Layer and the Chemical Weapons Convention, it addresses outcomes; in the case of the IHR and ILO Conventions C170 concerning Safety in the use of Chemicals at Work and C174 on Prevention of Major Industrial Accidents, reporting addresses activities.

### Reporting under the Montreal Protocol: a success story

Statistical data on ozone-depleting substances (ODS) for national reports are submitted yearly to the UN Environment Secretariat of the Vienna Convention and its Montreal Protocol (Ozone Secretariat). The compliance of each country with its obligations under the Montreal Protocol is then determined. All Parties report data on the production, export, import and destruction of the nine groups of ODS regulated under the Protocol. Reporting obligations are also established by Meetings of the Parties, which require relevant countries to submit information on specific issues such as uses of ODS as process agents and as feedstocks; approved essential or critical uses; exempted laboratory and critical uses; and reclamation facilities and their capacities. In addition, Parties are required to report every two years on research, public awareness and information exchange activities.

To provide support for the implementation of the Montreal Protocol in developing countries, National Ozone Units (NOUs) have been established in these countries at government level. In addition to submitting ODS data to the Ozone Secretariat annually, NOUs collect data on the production, export, import and destruction of the nine groups of substances regulated by the Protocol. This information is submitted to the Secretariat of the Multilateral Fund for the Implementation of the Montreal Protocol, which continuously monitors activities at the project level. Monitoring of projects involves periodic reporting to gauge a project's progress or lack of it. Projects experiencing delays and those with financial balances are monitored particularly closely and reported on to each Executive Committee meeting (Secretariat of

the Multilateral Fund for the Implementation of the Montreal Protocol 2018).

Beginning in 1990, and at least every four years thereafter, Assessment Panels prepare quadrennial reports on available scientific, environmental, technical and economic information. The Panels present these reports to the Parties to enable them to take informed decisions, with a view to strengthening the Protocol's control measures. There are currently three Panels: the Scientific Assessment Panel, the Technology and Economic Assessment Panel, and the Environmental Effects Assessment Panel. At least one year before each quadrennial assessment, the Parties set out in a decision the terms of reference for the assessments to be prepared by the Panels.

This well-considered preparatory process, and the effective performance of the NOUs, could be responsible for the high rate of compliance of the Parties to the Montreal Protocol with the reporting obligation. There has been a 100 per cent level of compliance with the reporting obligations since 1989, when the Protocol entered into force (UN 2018).

### Reporting under ILO Conventions C170 and C174

Reporting is to be carried out on a five-year cycle basis with respect to both ILO Convention C170 concerning Safety in the use of Chemicals at Work, and ILO Convention C174 on Prevention of Major Industrial Accidents. Normally the reporting format is built around the Convention text. Parties are asked to specify actions taken by answering open-ended questions corresponding to relevant obligations. The reporting formats specify that, in the first report, full information should be given concerning each question and each provision of the Convention. In subsequent reports information needs to be given only on new measures taken, and on questions about practical application of the Convention and the communication of the report to representative organizations of employees and workers (together with any observations received from these organizations). The reports should also contain responses to any comments by ILO supervisory bodies. The reporting rate under C170 and C174 has been universal. The ILO reports cannot be accessed online.

The reporting process involves two bodies: the Committee of Experts on the Application of Conventions and Recommendations (CEACR) and the Committee on the Application of Standards (CAS). The CEACR consists of independent legal experts who meet once a year. It provides comments, observations and direct requests on points of non-conformity and directly requests more information (ILO n.d. a). It also examines national reports and provides feedback to countries if it finds that further action is needed in order to give effect to certain provisions of the Conventions. The CEAR can express its satisfaction regarding positive actions taken, in response to comments and to provide an example for other countries addressing similar issues. Input from the CEACR feeds into the CAS, a subsidiary body of the International Labour Conference, which discusses how reporting obligations are fulfilled by countries and addresses serious violations (ILO n.d. b). The ILO has a well-considered structure in place to monitor compliance. Where there have been repeated cases of reporting failure, countries are named in CEACR and CAS reports.

## Reporting under the Basel and Stockholm Conventions

In the case of both the Basel and Stockholm Conventions, national reports include specific information on measures taken to implement the Convention; the effectiveness of those measures; designation of focal points to address Convention-related matters; and statistical data on the production, import, export and movement of the hazardous substances concerned and their impact on human health and the environment (Secretariat of the Basel Convention 2011; Secretariat of the Stockholm Convention 2018). In addition, for the Stockholm Convention an evaluation of effectiveness is carried out (see Part II, Ch. 3). An analysis of the process of national reporting under these Conventions can consider three aspects: how the overall group of parties complies with reporting obligations; how the process of national reporting has evolved over time; and how compliance with national reporting differs among groups of countries.

An initial finding has been that reporting rates are relatively low. Not all countries submit the required national reports, while some submissions are delayed, affecting the prompt availability of data to assess performance (Secretariat of the Basel, Rotterdam and Stockholm Conventions 2018). In addition, not all reports are available online. Only in recent reporting cycles (particularly with respect to the Basel Convention) have data been collected through electronic reporting systems. In the case of the Basel Convention, countries have reported an average 52 per cent of the times they were required to do so since 2001, while in the case of the Stockholm Convention they have met this obligation only 44 per cent of these times since 2002 (Secretariat of the Basel Convention 2011; Secretariat of the Stockholm Convention 2018).

Figure 2.1 shows compliance with national reporting obligations under the Basel and Stockholm Conventions in 2016: 19 countries (10 per cent of all Parties) had a 100 per cent reporting rate for the Basel Convention while 20 countries (11 per cent of all Parties) never submitted a report. In the case of the Stockholm Convention, 40 countries (22 per cent of all Parties) submitted all the required reports while

**Figure 2.1** Compliance with national reporting obligations, 2016: Basel and Stockholm Conventions

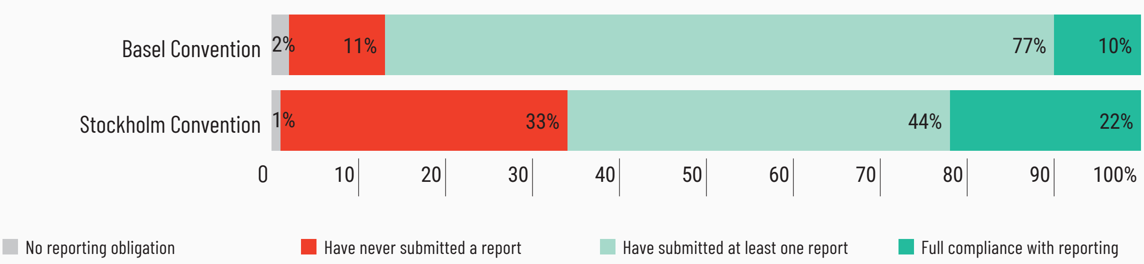
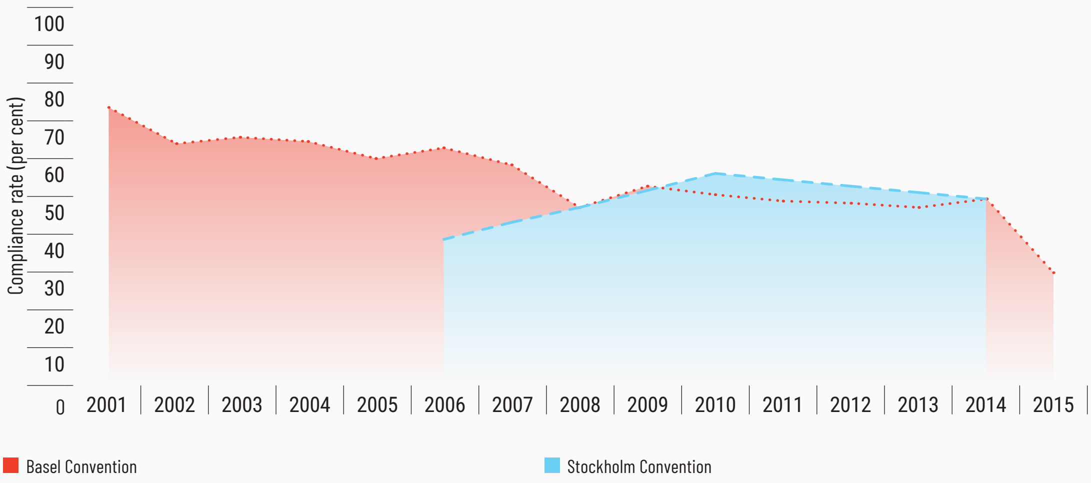


**Figure 2.2** **Historical evolution of general compliance with national reporting obligations: Basel and Stockholm Conventions, 2001-2015**

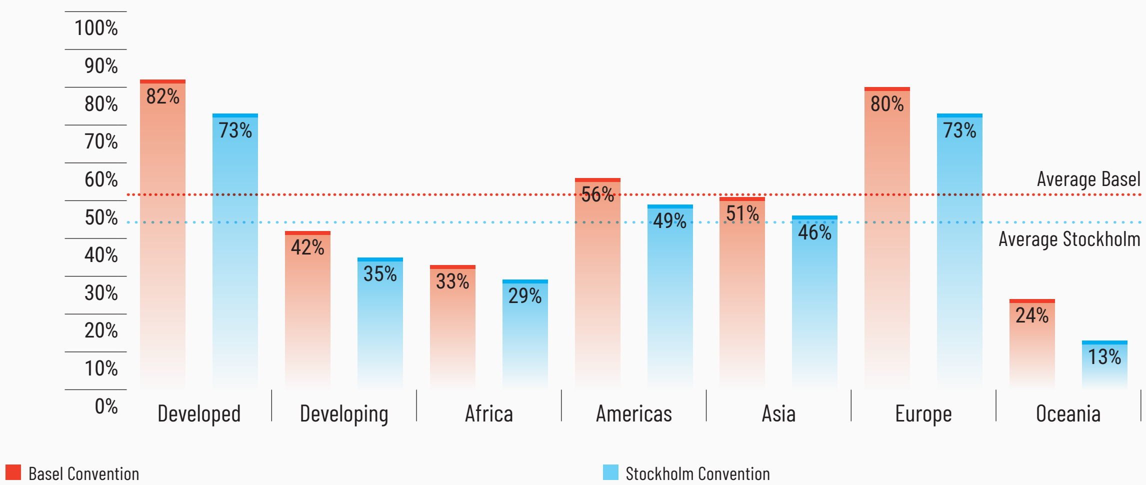



59 (33 per cent of all Parties) never submitted a report.

Figure 2.2 provides an overview of reporting rates between 2001 and 2015. For the Basel Convention the number of countries submitting a report every year fell from 74 per cent in 2001 to 30 per cent in 2015. For the Stockholm Convention there is a more positive trend, with the number of countries that submitted reports increasing from 39 per cent in 2002-2006 to 56 per cent in 2006-2010 and 49 per cent in 2010-2014. However, there is still a significant group of countries for which data are not available.

As shown in Figure 2.3, reporting rates in the period in the period 2001-2016 differ significantly between developed and developing countries, using the country designation of the UN Statistics Division (United Nations Statistics Division 2018). In the case of the Basel Convention, the average national reporting rate for developed countries (82 per cent) has been almost twice as high as that for developing countries (42 per cent). In terms of regions, countries in Europe have submitted reports an average 80 per cent of the time; in Oceania, on the other hand, there has been an average national reporting rate of 24 per cent of countries. In the case of the

**Figure 2.3** **Average national reporting rate 2001-2016, by category of countries (developed/ developing) and by regions: Basel and Stockholm Conventions**



Stockholm Convention, the rate for developed countries has been 73 per cent compared with 35 per cent for developing countries.

Reporting is a prerequisite for the monitoring and evaluation of implementation. National reporting indicators like those described above illustrate the characteristics of the reporting process and the challenges countries face in collecting the required information and completing reports. Factors such as lack of capacity at the national level, and the frequency of reporting cycles, may help explain some of the challenges. It is important to analyze the information in national reports to determine whether countries have established the institutional, technical and regulatory frameworks that can contribute to the solution of chemicals management problems. Otherwise, it will not be possible to determine the extent to which these agreements are being translated into national policies. It should be noted, however, that while limited data in national reports is challenging, this does not necessarily tell the whole story. Monitoring reports and the evaluation of effectiveness (as was done for the Stockholm Convention) also provide essential information. The outcomes of effectiveness evaluation for the Stockholm Convention are discussed in Part II, Ch. 3.

### Reporting under the WHO International Health Regulations (IHR) (2005): active support promotes effectiveness

Governments adopted the WHO International Health Regulations (IHR) (2005) in 2005. They entered into force in 2007. Countries had a five-year period during which to put in place core capacities. The initial reporting framework consisted of 20 indicators, including four performance levels on a continuum of progress. As of 2018, countries agreed to use the new State Party Self-Assessment Annual Reporting Tool which requires them to report on 24 indicators for developing 13 core capacities (WHO 2018a). In this reporting they move from exclusive self-evaluation to approaches that combine self-evaluation, peer review and voluntary external evaluations involving a combination of domestic and independent experts.

A Joint External Evaluation (JEE) framework has also been developed to provide independent analysis of countries' capacity to prevent, detect and respond to public health threats. Countries can request a JEE mission to help them identify the most urgent needs within their health system (WHO 2018b). JEEs are voluntary and assist countries in identifying the most critical gaps and prioritizing opportunities for enhanced preparedness and response. JEE mission reports, which are available online, provide an overview of a country's strengths and challenges, and proposed and/or agreed next steps towards increasing IHR core capacities.

Reporting for the IHR is high, reaching over 80 per cent in 2017 with a 100 per cent reporting rate by countries in Africa. An explanation could be that the WHO follows up directly with countries that have not reported through its headquarters or the relevant WHO Regional and Country Offices, depending on specific regional arrangements. Countries that have not reported are mentioned in the World Health Assembly report, putting peer pressure on these countries to report in the next round. WHO staff also follow up with country delegations that have not reported, which often triggers immediate action and increases reporting the following year.

**Box 2.1 The reporting mechanism for the WHO IHR (2005)**

Each indicator used in the International WHO IHR (2005) self-assessment process is graded on five performance levels. For each indicator five activities (or attributes) with different capability levels are listed in a checklist format, filled in according to activities at the country level. Attaining a given capability level requires that all the activities at lower levels are in place. For example, it is a prerequisite to have all the level 1 activities before examining activities at level 2. The goal is to reach or maintain level 5 for all 24 indicators. The level of achievement for each indicator is determined in countries, through workshops with stakeholders, and is reported annually.

Because of the involvement of senior officials in country delegations (which are normally headed by the Minister of Health), non-compliance with the IHR receives attention at a high political level.

### Reporting under the Minamata Convention on Mercury

Paragraph 1 of Article 21 of the Minamata Convention on Mercury requires each Party to report to the Conference of the Parties (COP) on the measures it has taken to implement the provisions of the Convention, the effectiveness of such measures, and possible challenges in meeting the objectives of the Convention. At the first Conference of the Parties (COP1) agreement was reached on the timing (every four years, with some questions to be reported on every two years) and format of reporting by the Parties, thereby taking into account lessons learned from reporting under other relevant treaties (Secretariat of the Minamata Convention on Mercury 2017).

## 2.2 Reporting schemes and indicators under voluntary international instruments

### The International Code of Conduct on Pesticide Management, the GHS and other activities

The International Code of Conduct on Pesticide Management and the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) are voluntary agreements which are widely used throughout the world. A number of other voluntary activities are also carried out in many countries. The number of countries active in voluntary agreements and activities is reflected in the IOMC indicators (see section 2.4 below). Reporting schemes under non-binding global policy instruments have varying degrees of formality.

Under the International Code of Conduct, governments, in collaboration with the FAO, the WHO and UNEP, are to monitor its observance and report on the progress made. The pesticide

industry is invited to provide relevant reports, while non-governmental organizations (NGOs) and other interested entities are invited to monitor and report on activities related to its implementation. Moreover, the governing bodies of the FAO, the WHO and UNEP should periodically review the relevance and effectiveness of the Code (FAO and WHO 2014). A process is in in place to supplement the provisions of the Code. While some governments and industry stakeholders regularly indicate adherence to the Code, regular reporting by governments and industry under the voluntary scheme has not been forthcoming. In some cases NGOs have submitted reports about cases of non-adherence, which are not publicly available. Furthermore, the relevant intergovernmental organizations track progress in various ways, e.g. through global surveys.

As regards the GHS, the Secretariat (hosted by the United Nations Economic Commission for Europe [UNECE]) collects publicly available information (including reports from members of the GHS Sub-Committee, NGOs, and other UN entities) to monitor the status of implementation (UNECE n.d.). A 2018 Organisation for Economic Cooperation and Development (OECD) Council Decision-Recommendation makes implementation of the GHS by OECD member countries mandatory. Monitoring implementation of this Council Act, as called for in the Act, would therefore include monitoring implementation of the GHS in these countries (OECD 2018; Stringer 2018).

## 2.3 Reporting scheme and indicators under SAICM

### The International Conference on Chemicals Management

The International Conference on Chemicals Management (ICCM), SAICM's oversight structure, carries out periodic reviews of SAICM and seeks to "receive reports from all relevant stakeholders on progress in implementation and disseminate information" (SAICM Secretariat 2018a). In 2009 the second session of the ICCM (ICCM2) adopted modalities for reporting, based on 20 indicators, to review progress towards the 2020 Goal (SAICM Secretariat 2009) (Box 2.2). These indicators were developed to cover the objectives of the OPS and relevant activities (rather than results). A baseline report was prepared in 2011 (SAICM Secretariat 2011). The questionnaire for measuring progress contains a mixture of mandatory and optional questions, with at least one mandatory question for each indicator. Most of the mandatory questions include a list of relevant activities alongside a series of check boxes. The average number of activities per indicator (as a percentage of all possible activities) is reported in the progress report. The same questionnaire applies to all stakeholders, including governments, intergovernmental organizations (IGOs) and NGOs.

To date, three SAICM reporting rounds have been completed for which information is available: 2009-2010, 2011-2013, and 2014-2016 (SAICM Secretariat 2012; SAICM Secretariat 2014a; SAICM Secretariat 2019). Reporting rates under SAICM exhibit a worrying downward trend: among governments, reporting rates dropped from around 40 per cent (78 submissions out of 194 governments) and 43 per cent (83 submissions out of 194 governments) in the first two rounds to 28 per cent (54 submissions out of 193 governments) in the third round, with data lacking in particular from African countries. Overall, reporting rates have been especially low among developing countries. SAICM also benefits from reporting by IGOs, civil society and the private sector, in some cases through collective reporting.

**Box 2.2 SAICM indicators of progress**

A. *Risk reduction*
1. Are implementing agreed chemicals management tools
2. Have mechanisms to address key categories of chemicals
3. Have hazardous waste management arrangements
4. Have activities that result in monitoring data on selected environmental and human health priority substances
5. Have mechanisms in place for setting priorities for risk reduction

B. *Knowledge and information*
6. Are providing information according to internationally harmonized standards
7. Have specific strategies for communicating information on chemical risks to vulnerable groups
8. Have research programmes
9. Have websites that provide information to stakeholders

C. *Knowledge and information*
10. Have committed themselves to implementation of the Strategic Approach
11. Have a multi-stakeholder coordinating mechanism
12. Have mechanisms to implement key international chemicals priorities

D. *Capacity building and technical cooperation*
13. Are providing resources for capacity building and technical cooperation with other countries
14. Have identified and prioritized their capacity building needs for the sound management of chemicals
15. Are engaged in regional cooperation on issues relating to the sound management of chemicals
16. Have development assistance programmes which include the sound management of chemicals
17. Have projects supported by the SAICM Quick Start Programme (QSP) Trust Fund
18. Have projects for the management of chemicals supported by other sources of funding (not QSP funding)

E. *Illegal international traffic*
19. Have mechanisms to prevent illegal traffic in toxic, hazardous and severely restricted chemicals individually
20. Have mechanisms to prevent illegal traffic in hazardous waste

The second progress report identified some gaps in the indicators, including illegal national trade (such as through informal markets); the extent of national funding for chemicals management through government budgets and official development assistance; and the use of non-chemical alternatives and agroecological approaches. The report recommended complementing activity-based indicators with objectively verifiable results-based indicators which quantify reductions in health and environmental impacts of chemical use (SAICM Secretariat 2014a). The third report included for the first time progress on the IOMC indicators of progress, in order to explore the interlinkages with the 20 SAICM indicators, cross-reference the data collected through the SAICM survey, and present a better picture of global progress towards the sound management of chemicals. However, the report noted that it is not possible to present a consistent global picture of progress given the low reporting rate, and the lack of adequate data, across regions (SAICM Secretariat 2019). Since the conclusions are not fully reliable, and are not representative of the true status of global progress towards the sound management of chemicals, the report recommends encouraging greater participation in reporting by governments in the next reporting period.

## Relationship between the OPS, the GPA and the SAICM indicators of progress

The SAICM framework for action consists of three main elements (Part II, Ch. 1, Box 1.1). The OPS includes five thematic objectives with 46 specific objectives, while the GPA includes 273 activities (each with an indicator of progress) which have been grouped into 36 work areas. These two documents have a different status, as the OPS constitutes a negotiated outcome and the GPA has not been formally adopted. Their content does not match entirely; for example, the GPA includes work areas which are not covered by the OPS (e.g. regarding integrated programmes, protected areas and contaminated sites). The 20 SAICM indicators of progress, alongside the 299 GPA indicators (which may

**Box 2.3** **The SAICM Overall Orientation and Guidance (OOG) (SAICM Secretariat 2014b)**

The following set of 11 basic elements have been recognized in the SAICM's OOG as critical at the national and regional levels for the attainment of sound chemicals and waste management:

1. Legal frameworks that address the life cycle of chemicals and waste
2. Relevant enforcement and compliance mechanisms
3. Implementation of chemicals and waste-related multilateral environmental agreements, as well as health, labour and other relevant conventions and voluntary mechanisms
4. Strong institutional frameworks and coordination mechanisms among relevant stakeholders
5. Collection and systems for the transparent sharing of relevant data and information among all relevant stakeholders using a life-cycle approach, such as implementation of the GHS
6. Industry participation and defined responsibility across the life cycle, including cost recovery policies and systems as well as the incorporation of sound chemicals management into corporate policies and practices
7. Inclusion of the sound management of chemicals and waste in national health, labour, social, environment and economic budgeting processes and development plan
8. Chemicals risk assessment and risk reduction through the use of best practices
9. Strengthened capacity to deal with chemical accidents, including institutional strengthening for poisons centres
10. Monitoring and assessing the impacts of chemicals on health and the environment
11. Development and promotion of environmentally sound and safer alternatives

also be used for certain specific activities), can present a confusing impression with respect to SAICM implementation. The lack of strategic focus resulting from the number of guidance documents – with varying content, emphasis and status – has been cited as one of the weaknesses of SAICM that has hampered implementation and follow-up on progress (Honkonen and Khan 2017; Urho 2018). Most importantly, the 20 SAICM progress indicators and the 273 GPA indicators provide contradictory guidance for monitoring progress.

In 2015 the fourth session of the ICCM (ICCM4) endorsed the Overall Orientation and Guidance (OOG) for achieving the 2020 goal of sound management of chemicals (OOG). The OOG identifies 11 basic elements considered to be crucial at the national and regional levels for achieving the sound management of chemicals and waste (SAICM Secretariat 2014b, paragraph 19). Observers have remarked that the OOG is beneficial to stakeholders, as it consolidates the necessary elements of what is essentially an extremely broad plan encompassing the 299 activities listed in the GPA (Honkonen and Khan 2017). When evaluating the achievements of SAICM, it is therefore essential to understand the monitoring instrument which is applied and its context.

## 2.4 Activities tracked by the IOMC indicators

### An initiative on simple indicators of progress

The Inter-Organization Programme for the Sound Management of Chemicals (IOMC) brings together nine intergovernmental organizations actively involved in chemical safety: the FAO, the ILO, the UN Development Programme (UNDP), UNEP, the UN Industrial Development Organization

**Table 2.1 IOMC Indicators and linkages to other policy instruments**

| IOMC indicator | Inherently SAICM | Other voluntary agreement | Binding agreement | Links to Global Plan of Action activities | Links to Overall Orientation and Guidance elements |
|---|---|---|---|---|---|
| 1. No. of countries with national profiles | o | | | 1, 207, 211 | 4, 5 |
| 2. No. of countries with a Pollutant Release and Transfer Register (PRTR) | o | | | 124-126, 177-180 | 10 |
| 3. No. of countries with a poisons centre | o | | | 35, 221, 237 | 9, 10 |
| 4. No. of countries with controls for lead in decorative paint | o | | | 57 | 2, 8 ,10 |
| 5. No. of countries that have implemented pesticide legislation based on the International Code of Conduct on Pesticide Management | | o | | 23, 31, 189 | 3 |
| 6. No. of countries that have achieved core capacities for chemicals under the International Health Regulations (2005) | | | o | | 2 |
| 7. No. of countries that have Implemented the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) | | o | | 22, 99-101, 168, 248-250 | 3, 5 |
| 8. No. of Parties to the Basel, Rotterdam, Stockholm and Minamata Conventions | | | o | 169 | 3 |

(UNIDO), the UN Institute for Training and Research (UNITAR), the WHO, the World Bank and the OECD. These organizations coordinate their chemicals management activities and have an important role in SAICM, as 80 per cent of the activities of the GPA make reference to the involvement of IOMC organizations (SAICM Secretariat 2014b). In 2015 the IOMC developed a set of indicators to help IOMC organizations track progress relevant to SAICM by analyzing data from verifiable sources for which global data are available. The IOMC participating organizations have undertaken work in all these areas to support countries. The indicators are intended to provide additional information to complement data provided through reporting which has gaps due to low reporting rates. They are in use and are published on the IOMC website (IOMC 2010).

The IOMC indicators address legally binding agreements, but also a number of voluntary agreements such as the International Code of Conduct on Pesticide Management and the GHS, as indicated in Table 2.1. The table shows linkages to GPA activities (because the GPA makes abundant reference to IOMC participating organizations) and to the 11 basic elements of the OOG (because these have been established in SAICM as crucial basic elements at the national and regional level).

## 2.5 Reporting scheme and indicators under the 2030 Agenda for Sustainable Development

As explained in Part II, Ch. 1, a number of SDGs and targets under the 2030 Agenda are directly or indirectly relevant for the sound management of chemicals and waste. The existence of the SDG targets means new indicators and reporting obligations have been brought into the system of global governance for chemicals and waste. The High-Level Political Forum (HLPF), supported by the UN Economic and Social Council, has been designated as the main follow-up and review mechanism for progress on the SDGs. The HLPF conducts thematic reviews in a four-year cycle. For each meeting of the HLPF, countries are invited to prepare Voluntary National Reviews (VNRs) that are expected to contain useful information, identify best practices and challenges, and provide lessons that will contribute to implementation of the 2030 Agenda. The VNRs can also make it possible to identify opportunities for multi-stakeholder collaboration and the establishment of new partnerships to implement the SDGs.

Table 2.2 shows SDGs related to the management of chemicals and waste, with six targets and 11 indicators. The custodian and partner agencies in charge of the indicator-related work are also shown, as well as linkages to OOG elements (UN 2016; Inter-agency and Expert Group on Sustainable Development Goal Indicators 2018).

To monitor progress on chemicals-related SDG targets, interaction with multilateral agreements and the targets and indicators established by them is critical. Implementation of the chemicals- and waste-related multilateral agreements provides information relevant to Target 12.4 and Indicator 12.4.1 regarding the number of parties to the chemicals Conventions; the IHR provide information on health-related risks under Target 3.

There are clear linkages between the SDGs and SAICM. In 2017 and 2018, in the ongoing SAICM Intersessional process considering the Strategic Approach and the sound management of chemicals and waste beyond 2020, progress reporting, proposed objectives (derived from the OOG), related milestones, and links to the SDGs and the 2030 Agenda were discussed and areas were identified where SAICM indicators could strategically relate to the SDG targets (SAICM Secretariat 2017; SAICM Secretariat 2018b). Furthermore, the WHO has developed a Chemicals Road Map to enhance engagement by the health sector in SAICM towards the 2020 goal and beyond, addressing SDGs 3, 6 and 12 (WHO 2017). The Road Map includes a number of actions related to better measuring progress and improving indicators.

**Table 2.2** SDGs 3, 6, 11 and 12 with targets, indicators, custodian and partner agencies, and linkages to OOG elements

| Goal | Target | Indicator, with custodian (C) and partner (P) agencies | Linkages to OOG elements |
|---|---|---|---|
| 3 GOOD HEALTH AND WELL-BEING | **3.9.** By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination | **3.9.1** Mortality rate attributed to household and ambient air pollution<br>*C: WHO; P: UNEP*<br>**3.9.2** Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All [WASH] services)<br>C: WHO; P: UNEP<br>**3.9.3** Mortality rate attributed to unintentional poisoning<br>*C: WHO; P: UNEP* | 1 3 5 7 8 10 11 |
| 6 CLEAN WATER AND SANITATION | **6.3** By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally | **6.3.1** Proportion of wastewater safely treated<br>*C: WHO, UN Habitat, UNSD;*<br>*P: UNEP, OECD, Eurostat*<br>**6.3.2** Proportion of bodies of water with good ambient water quality<br>*C: UNEP; P: UN Water* | 1 3 7 |
| 11 SUSTAINABLE CITIES AND COMMUNITIES | **11.6** By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management | **11.6.1** Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities<br>*C: UN Habitat, UNSD ; P: UNEP*<br>**11.6.2** Annual mean levels of fine particulate matter (e.g. $PM_{2.5}$ and $PM_{10}$) in cities (population weighted)<br>*C: WHO; P: UN Habitat, UNEP OECD* | 3 7 9 |
| 12 RESPONSIBLE CONSUMPTION AND PRODUCTION | **12.4** By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment | **12.4.1** Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement<br>*C: UNEP*<br>**12.4.2** Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment<br>*C: UNSD, UNEP; P: OECD, Eurostat* | 1 3 4 5 6 7 8 9 10 11 |
| | **12.5** By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse | **12.5.1** National recycling rate, tonnes of material recycled<br>*C: UNSD, UNEP; P: OECD, Eurostat* | 1 3 4 5 6 7 8 9 10 11 |

# 3/ Achieving the 2020 goal: what do we know?

## Chapter Highlights

Although concerted action has been taken through multilateral treaties on specific hazardous chemicals and issues of global concern, implementation gaps remain.

Progress has also been made through voluntary international instruments, including the International Code of Conduct on Pesticide Management and the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), but implementation gaps remain.

Regional cooperation, including through regional economic integration organizations, has assumed a prominent role in addressing chemicals and waste.

National profiles on chemicals management have produced country baseline information in many countries through multi-sectoral and multi-stakeholder collaboration.

The knowledge base on chemicals has been enhanced, among others through national inventories, hazard assessments, and Pollutant Release and Transfer Registers (PRTRs).

Many countries have made progress in enacting laws; creating programmes and plans; and implementing and aligning policies to create knowledge and to manage chemicals of concern.

The integrated approach to financing has mobilized significant resources, but has not matched the need and demand for support expressed by developing countries and economies in transition.

Illegal international traffic of hazardous waste and counterfeit products remains a priority.

An independent evaluation found the Strategic Approach to International Chemicals Management (SAICM) to be a unique framework, but pointed out weaknesses.

This chapter provides insights into the extent to which progress has been made towards achieving the 2020 goal. As implementation of relevant international instruments was explicitly referred to in the 2002 Johannesburg Plan of Implementation (JPOI), and since the multilateral treaties contribute across the five objectives of the OPS, they are discussed separately in the second section. The subsequent analysis of action taken, including through voluntary international instruments, is organized around the five objectives of the OPS: knowledge and information; risk reduction; governance; capacity building and technical cooperation; and illegal international traffic. This approach follows, with some adjustments, the institutional architecture in the international chemicals and waste cluster. In many cases activities discussed under one of the objectives may also contribute to the achievement of other objectives, as also reflected in the GPA. One such example is the GHS, discussed here under knowledge and information although it also contributes to risk reduction. The chapter concludes with a discussion of insights from stakeholder reporting on SAICM implementation, as well as the independent evaluation of SAICM, to provide additional insights relevant for assessing progress towards the 2020 goal.

Measuring the success of international agreements and frameworks has two aspects. The first concerns activities undertaken by Parties to meet their obligations or (in the case of voluntary international instruments) activities undertaken by stakeholders to implement voluntary commitments or agreed actions. Such activities include adoption of regulations, institutional arrangements, and awareness-raising activities. It is also essential, but more difficult, to obtain insights into whether agreements and frameworks are achieving their impact-oriented objectives (i.e. better protection of human health and the environment). The approach taken here to assess progress takes into account that a consolidated international results and indicators framework for chemicals and waste (which could have been used as an organizing framework to assess progress) is not in place.

## 3.1 Implementation of multilateral treaties on chemicals and waste

On specific hazardous chemicals and issues of global concern, the international community has taken concerted action through multilateral, legally binding treaties. While some experts agree that multilateral, legally binding treaties are effective, others argue that they cannot fully resolve the problems they were designed to address and point out that they are highly dependent on countries' capacity, political will and resources (Brown-Weiss and Jacobson 1998; Young 2011; Seelarbokus 2014; Sand 2016). As described below, progress towards the 2020 goal has been made through multilateral treaties on chemicals and waste. Yet implementation challenges remain.

### 3.1.1 The Montreal Protocol

The Montreal Protocol on Substances the Deplete the Ozone Layer (see Part II, Ch. 1, 2) was adopted in 1987, entered into force in 1989 and has 197 Parties. As noted in more detail in Part I, Ch. 5, 7, implementation of the Montreal Protocol has resulted in significant achievements. These include the phase-out of 99 per cent of ozone-depleting chemicals (Secretariat of the Vienna Convention and its Montreal Protocol 2018), averted emissions of 135 billion tonnes of carbon dioxide equivalent ($CO_2$-eq) to the atmosphere (Molina *et al.* 2009), and avoidance of much more severe ozone depletion (World Meteorological Organization [WMO] 2018a; WMO 2018b). It is particularly noteworthy that 142 out of 147 developing country partners met the 100 per cent phase-out target for chlorofluorocarbons (CFCs), halons and other ODS in 2010 (Rae and Gabriel 2012). Human health benefits achieved by the implementation of the Montreal Protocol have been realized primarily through the prevention of large increases in ultraviolet (UV) radiation in most of the world's inhabited regions. It is estimated that at least 100 million cases of skin cancer and many million cases of cataracts will be avoided by the end of this century as a result of implementation of the Protocol (UNEP 2015) (for more details, see Part I, Ch. 7).

Hydrofluorocarbons (HFCs) have been the most commonly used substitutes for ozone-depleting substances, especially for hydrochlorofluorocarbons (HCFCs). While HFCs do not deplete the ozone layer, they have a high global warming potential. The Kigali Amendment to the Montreal Protocol, which was agreed by Parties in 2016 and will enter into force in 2019, "is projected to reduce future global average warming in 2100 due to [HFCs] from a baseline of 0.3-0.5°C to less than 0.1°C" (WMO 2019).

A number of factors are responsible for the success of the Montreal Protocol (Rae and Gabriel 2012). In addition to a high level of cooperation and commitment by the international community, the following have been cited as determinants of success:

- To encourage countries to join the Protocol (and to prevent companies that manufacture or use CFCs and all other substances controlled by the Montreal Protocol from shifting operations to non-Parties), the Protocol restricts trade in CFCs and CFC-related products with non-Parties. It also contains a number of provisions restricting trade in controlled substances between Parties (Center for International Environmental Law [CIEL] 2015).

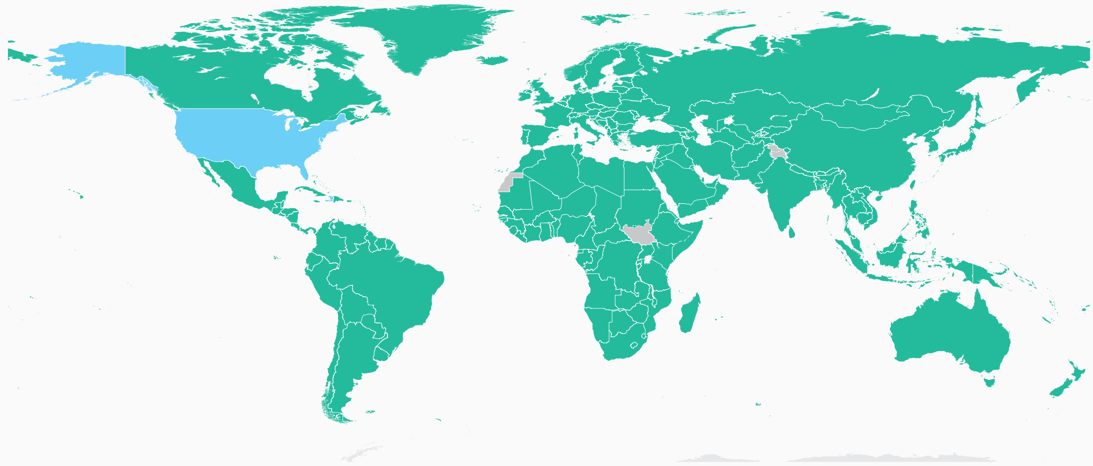
- The Protocol has provided a stable framework, allowing industry to plan long-term research and innovation.

- The three Assessment Panels of the Montreal Protocol (see Part II, Ch. 2) have been the pillars of the ozone protection regime since the beginning of the Protocol's implementation. By providing independent technical and scientific assessments and information, the Panels have helped the Parties reach solid and timely decisions on often complex matters. Panel experts have helped give countries the confidence to start their transition to chemicals that do not deplete the ozone layer. The compliance procedure was designed from the outset to be non-punitive in cases where countries were not in compliance.

- The Multilateral Fund for the Implementation of the Montreal Protocol (see Part II, Ch. 2) provides funding for developing countries to help them meet their compliance targets. It also provides institutional support to help these countries build capacity within their governments.

Even in the case of success stories such as the Montreal Protocol, implementation may present challenges. For example, it emerged in 2018 that the production and use of trichlorofluoromethane (CFC-11), a powerful ozone-depleting substance banned under the Montreal Protocol and also a potent greenhouse gas, may be ongoing (Montzka *et al.* 2018).

**Figure 3.1** **Parties to the Basel Convention, as at January 2019 (adapted from Secretariat of the Basel Convention 2019a)**

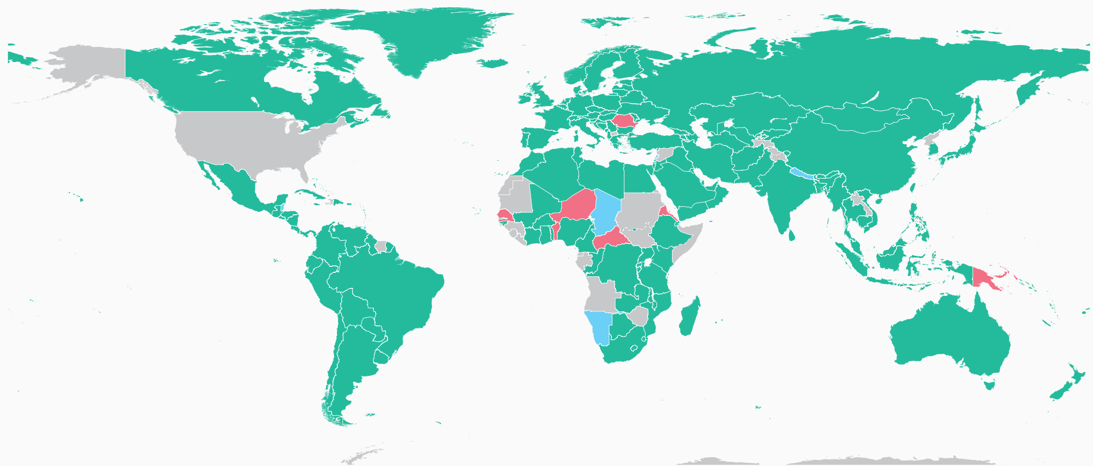



## 3.1.2 The Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal (see Part II, Ch. 1, 2) was adopted in 1989 and entered into force in 1992. It has 186 Parties, compared with 173 in 2010 (Secretariat of the Basel Convention 2019a) (Figure 3.1).

The Basel Convention has an Implementation and Compliance Committee which is a subsidiary body of the Conference of the Parties (COP) to the Convention. The level of implementation can be measured across specific countries and regions. For example, national report templates ask Parties to report on the status of the control procedure for transboundary movements of waste, including through the use of notification and movement document forms. A detailed analysis of their performance shows that many

**Figure 3.2** **Basel Convention implementation: Parties which have used the option to adopt a national definition of hazardous waste, as at January 2019 (based on Secretariat of the Basel Convention 2019b)**



are making important progress. Under the Convention, Parties have the option to adopt a national definition of hazardous wastes. Figure 3.2 shows the extent to which they have used this option (Secretariat of the Basel Convention 2019b).

The Basel Convention has also strengthened Parties' capacity for environmentally sound management of various types of waste through the development of a series of technical guidelines covering, among others, wastes that consist of, contain or are contaminated with (for example) mercury, polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins and dibenzofurans (Secretariat of the Basel Convention 2011).

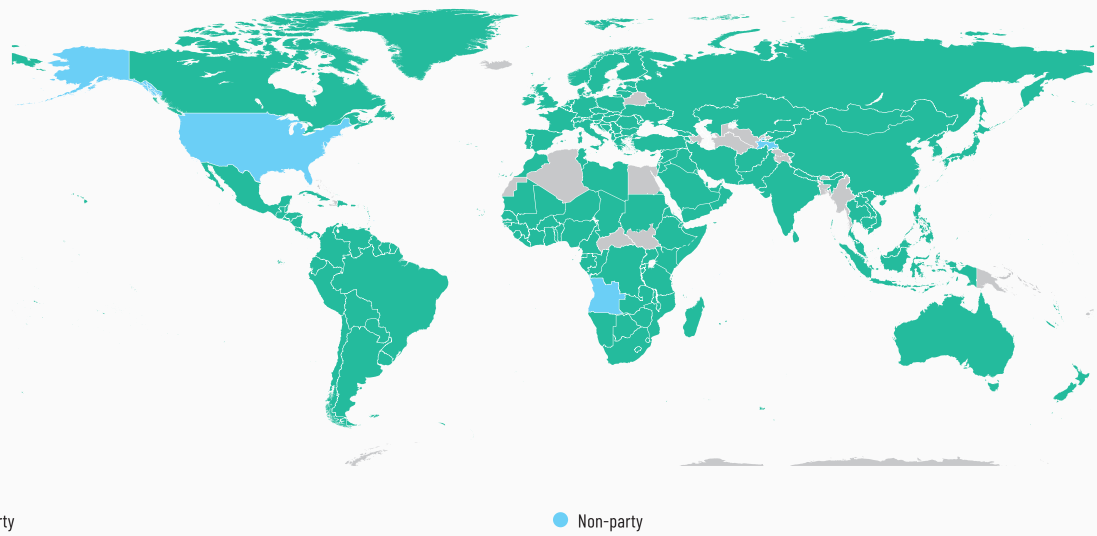
In 2011 the COP adopted a strategic framework for the implementation of the Basel Convention for 2012-2021 consisting of a vision; guiding principles; strategic goals and objectives; means of implementation; indicators for measuring achievement; and performance and evaluation. For the mid-term evaluation in 2016, 35 responses were received from Parties. In its decision BC-13/1, the COP noted the low level of submissions of information to enable the mid-term evaluation and agreed on a new approach to preparing the final evaluation of the strategic framework in time for the 15th meeting of the COP in 2021 (Secretariat of the Basel Convention 2017).

### 3.1.3 The Rotterdam Convention

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (see Part II, Ch. 1, 2) was adopted in 1998, entered into force in 2004 and has 161 Parties, compared with 140 in 2010 (Secretariat of the Rotterdam Convention 2019) (Figure 3.3). It facilitates information exchange on the international trade of certain hazardous chemicals by providing for a national decision-making process concerning the import and export of such chemicals, and by disseminating those decisions to Parties for collective consideration at the international level in accordance with the procedures of the Convention.

There is no reporting obligation under the Rotterdam Convention. However, the Prior Informed Consent (PIC) scheme is an indicator that reflects the extent to which countries are achieving results on the objectives to which they have agreed. The PIC scheme requires an exporting party to receive prior consent from an importing party before it exports to that country a chemical listed under the Convention. The second progress report in 2013 noted that the Secretariat had received 45 notifications, from 16 Parties, of a final regulatory action to ban or severely restrict a chemical during the reporting period 2012-2013. It also highlighted that a total

**Figure 3.3** Parties to the Rotterdam Convention, as at January 2019 (adapted from Secretariat of the Rotterdam Convention 2019)



of 4,500 import responses had been submitted by 135 Parties for Annex III chemicals since the Convention entered into force (Secretariat of the Rotterdam Convention 2013). As the PIC procedure has evolved, there have been several challenges at the national level regarding effective implementation of the obligations. They have included the financial and technical capacity to manage customs systems, and to review all requests for imports and control them.

Article 17 of the Convention requires the COP to develop and approve procedures and institutional mechanisms for determining non-compliance and for the treatment of Parties found to be non-compliant. The topic has been discussed at an Open-ended Ad-Hoc Working Group as well as at each COP. However, to date no final decision has been taken on this matter. The COP, at its eighth meeting in 2017, established a working group to identify a set of prioritized recommendations for enhancing the effectiveness of the Convention, and to identify further steps in this respect for consideration by the Parties.

The Rotterdam Convention has contributed to the establishment of key parameters for the trade of hazardous substances. This is important with respect to the transfer of information to developing countries. The Convention has also created a policy space for collaboration on trade in hazardous substances and materials with other organizations, such as the World Customs Organization (WCO), and with the GHS.

### 3.1.4 The Stockholm Convention

The Stockholm Convention on POPs (see Part II, Ch. 1, 2) was adopted in 2001, entered into force in 2004 and has 182 Parties, up from 172 in 2010 (Secretariat of the Basel, Rotterdam and Stockholm Conventions [BRS Secretariat] 2018; Secretariat of the Stockholm Convention 2019a) (Figure 3.4).

Article 7 of the Stockholm Convention requires Parties to develop and periodically update National Implementation Plans (NIPs) to meet their obligations under the Convention. Depending on a country's specific situation in the context of the Convention, NIPs could provide information about all measures taken on POPs, such as legislative and policy measures; the preparation of action plans; the setting up of monitoring schemes related to the occurrence and releases of POPs; and efforts to reduce their environmental concentrations. To date, 91 per cent of Parties have submitted NIPs covering the 12 initial POPs (UNEP and Secretariat of the Stockholm Convention 2017a) (Figure 3.5). NIPs are intended to be "living documents" and to be periodically updated as the Convention evolves and new substances are listed in the annexes, provided a Party is bound by the amendment

**Figure 3.4** Parties to the Stockholm Convention, as at January 2019 (adapted from Secretariat of the Stockholm Convention 2019a)

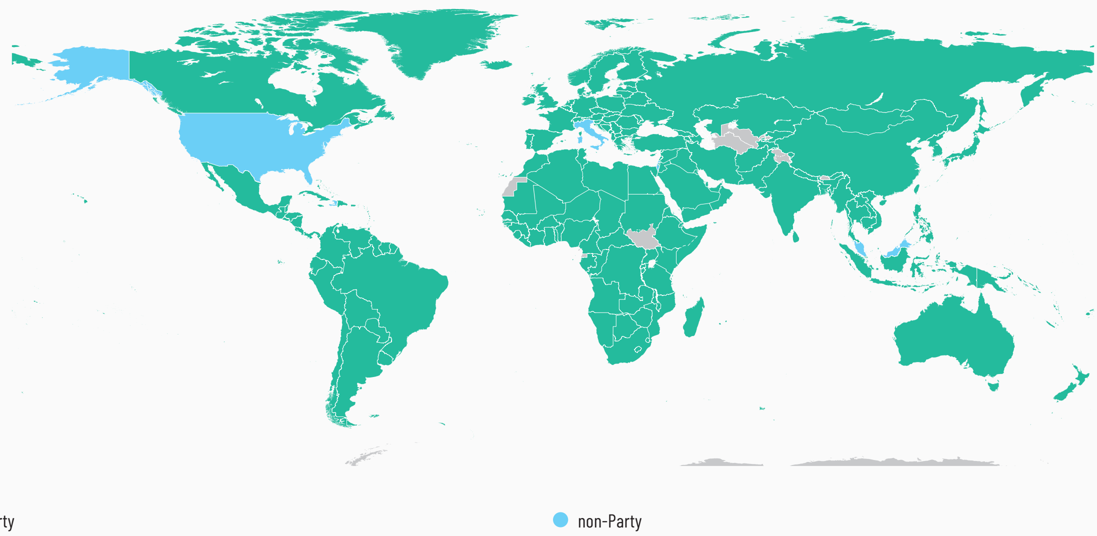
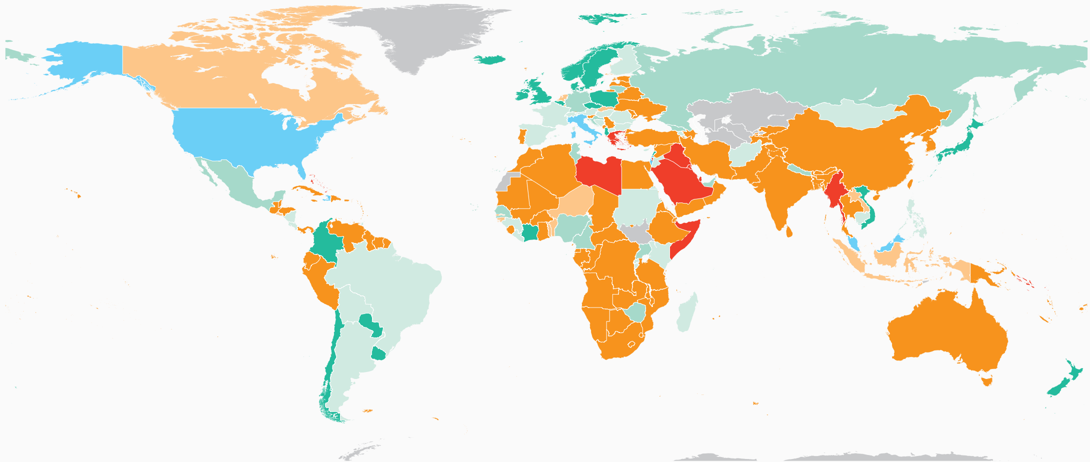


**Figure 3.5** Countries with National Implementation Plans (NIPs) under the Stockholm Convention, as at January 2019 (based on Secretariat of the Stockholm Convention 2019b)




or has deposited its instrument of ratification. However, since 2011 only around one-quarter of NIPs have been updated to reflect the inclusion of new substances (UNEP and Secretariat of the Stockholm Convention 2017b).

The Stockholm Convention includes periodic effectiveness evaluations, which have so far been carried out twice, in 2009 and 2017, drawing upon many sources of information including reporting, NIPs, monitoring data and non-compliance information. The 2017 effectiveness evaluation concluded that "the Convention provides an effective and dynamic framework to regulate POPs throughout their lifecycle, addressing the production, use, import, export, releases, and disposal of these chemicals worldwide" (UNEP and Secretariat of the Stockholm Convention 2017b). In addition, it reported that the Convention had put in place the mechanisms required to support Parties. However, the evaluation also noted areas for further work, including lack of regulatory and assessment schemes for industrial chemicals, limited availability of data from national inventories, and the existence of large stockpiles of obsolete pesticides. The evaluation report included recommendations to improve implementation; create procedures and mechanisms to support countries in compliance; and address the challenge of limited reporting and availability of data in national reports and national implementation plans.

The effectiveness evaluation also found that limited progress had been made towards the environmentally sound management of PCBs by 2028 (Secretariat of the Stockholm Convention 2017; UNEP and Secretariat of the Stockholm Convention 2017b) (Table 3.1). An estimated 1-1.5 million tonnes of technical grade PCBs have been produced. Each tonne has generated at least 20 tonnes of PCB waste, posing significant challenges for countries with limited capacity for the environmentally sound management of PCB. It is estimated that 3 million tonnes of PCB liquids and equipment were eliminated by the Parties to the Stockholm Convention by 2015. Most of that progress was made after the Convention entered into force in 2004, indicating its effectiveness. However, it has been estimated that around 14 million tonnes of PCB liquids and equipment still need to be eliminated. This means 83 per cent of the total amount of PCB liquids and equipment remains to be destroyed by 2028 (Secretariat of the Stockholm Convention 2017; UNEP and Secretariat of the Stockholm Convention 2017b).

The Global Monitoring Plan (GMP) was established to provide Parties with a harmonized framework for data collection and monitoring of the presence

**Table 3.1** **Estimates of progress made towards elimination of PCBs use per UN region, 1990-2015 (UNEP and Secretariat of the Stockholm Convention 2017b, p. 73)**

| Region | Eliminated | | To be eliminated | | Total |
|---|---|---|---|---|---|
| | Tonnes | Share (%) | Tonnes | Share (%) | |
| Africa | 6,056 | 2 | 269,736 | 98 | 275,792 |
| Asia-Pacific | 2,017,916 | 14 | 12,374,821 | 86 | 14,392,736 |
| Central and Eastern Europe | 111,009 | 19 | 482,076 | 81 | 593,085 |
| Latin America and the Caribbean | 76,772 | 14 | 484,768 | 86 | 561,540 |
| Western Europe and Others | 744,267 | 64 | 415,464 | 36 | 1,159,731 |
| **All** | **2,956,019** | **17** | **14,026,865** | **83** | **16,982,885** |

of POPs. It is the backbone of the effectiveness evaluation. The GMP provides information on trends in the occurrence of POPs in humans and the environment. The first GMP report (Secretariat of the Stockholm Convention 2009) provided information on baseline concentrations of 12 legacy POPs. The second report (UNEP and Secretariat of the Stockholm Convention 2017a) provided the first indications of changes in concentrations of legacy POPs, as well as baseline information on newly listed POPs. Monitoring results indicate that concentrations of some POPs may be decreasing while trends are mixed for others (see Part I, Ch. 6).

### 3.1.5 The Minamata Convention

The Minamata Convention on Mercury was adopted in 2013 and entered into force in 2017 (see Part II, Ch. 1, 2). As of January 2019, 101 States and the EU had deposited instruments of ratification (or acceptance, approval or accession) (UNEP 2019a) (Figure 3.6).

Like the Basel Convention, the Minamata Convention has an Implementation and Compliance Committee which is a subsidiary body of the Conference of the Parties (UNEP 2018a). There is also a periodic effectiveness evaluation, as in the case of the Stockholm

**Figure 3.6** **Parties to the Minamata Convention, as at January 2019 (adapted from UNEP 2019a)**

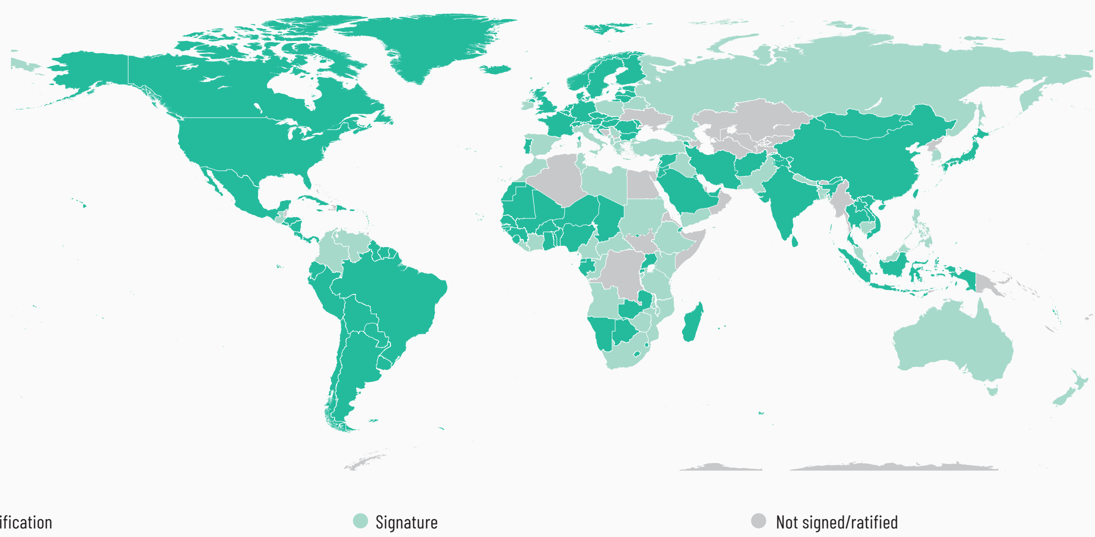
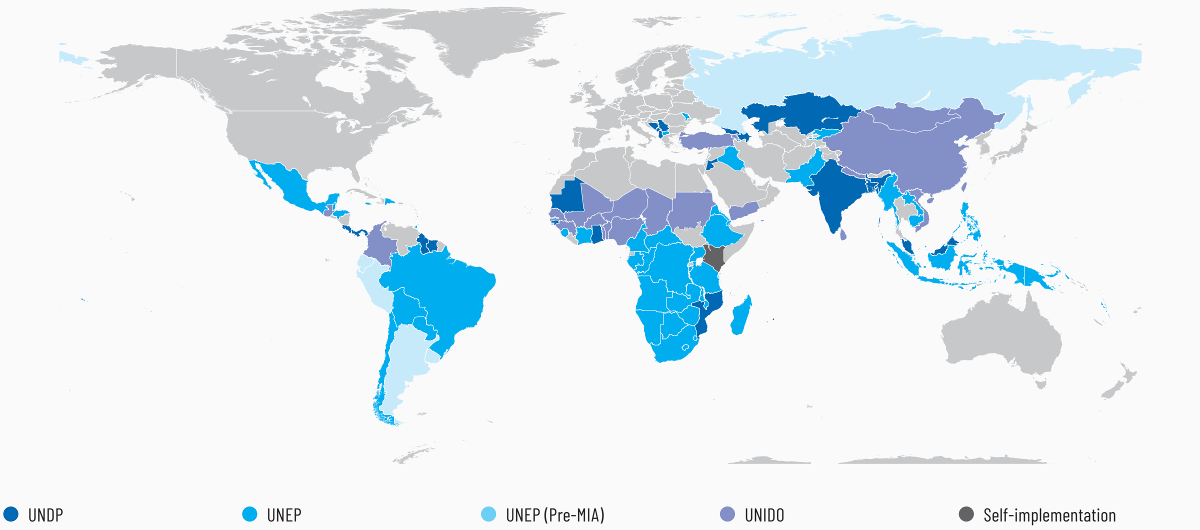


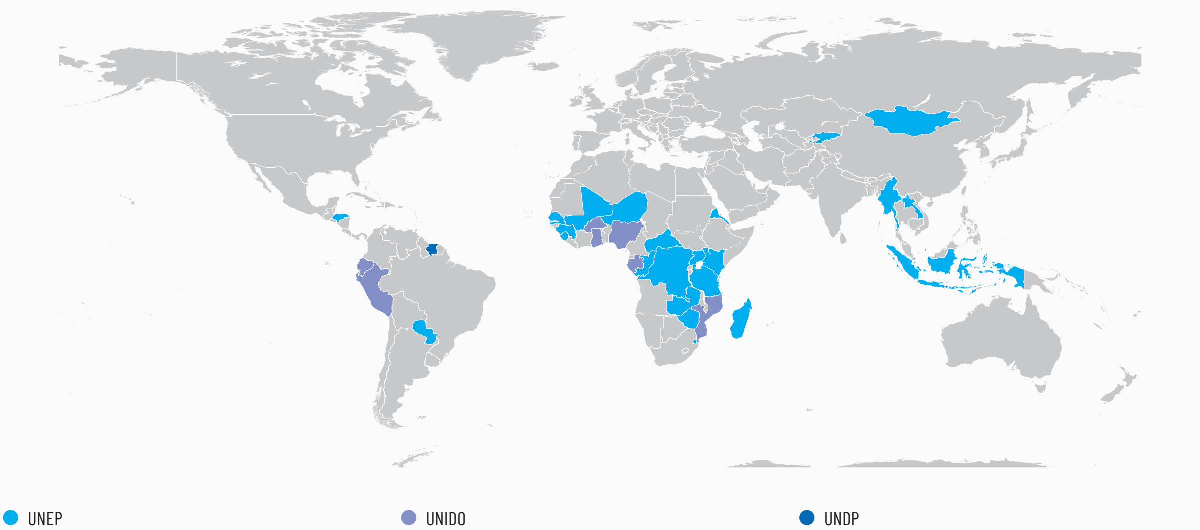
**Figure 3.7** Countries which have undertaken Minamata Initial Assessments (MIAs), as at January 2019 (adapted from UNEP 2019a)




Convention. The Minamata Convention defines a financial mechanism to support developing country Parties, and Parties with economies in transition, in meeting their obligations. It includes the Global Environment Facility (GEF) Trust Fund and a Specific International Programme (SIP) to Support Capacity-Building and Technical Assistance. The first five projects were approved by the Governing Board of the SIP in October 2018 (Secretariat of the Minamata Convention on Mercury 2018). The GEF supports, among others, enabling activities for eligible Parties to strengthen national capacity towards ratification and build national capacity to meet future obligations, particularly undertaking Minamata Initial Assessments (MIAs) (Figure 3.7).

Artisanal and small-scale gold mining (ASGM) is a major source of anthropogenic emissions of mercury. The Minamata Convention requires Parties with more than insignificant ASGM using mercury to extract gold from ore to develop and implement National Action Plans (NAPs). Figure 3.8 shows the Parties that are developing

**Figure 3.8** Parties with National Action Plans (NAPs) for artisanal and small-scale gold mining, as at January 2019 (adapted from UNEP 2019a)



**Box 3.1** **Synergies across multilateral treaties on chemicals and waste**

In 2011 the COPs to the Basel, Rotterdam and Stockholm Conventions adopted substantively identical decisions to further cooperation and coordination. To create more synergies among the three Conventions, it was decided to hold joint sessions of two or three of the COPs on joint issues. The objectives of holding these meetings in a coordinated manner are to strengthen implementation of the three Conventions at the national, regional and global levels; promote coherent policy guidance; and enhance efficiency in the provision of support to Parties (Secretariat of the Basel, Rotterdam and Stockholm Conventions [BRS Secretariat] 2018).

Regarding the last objective, the Secretariat structure for the Conventions was streamlined. In 2012 the Secretariats of the Basel and Stockholm Conventions, together with UNEP (which is part of the Rotterdam Convention Secretariat), moved from three separate Secretariats with a programmatic structure to a single Secretariat with a matrix structure serving all three Conventions. Greater cooperation and coordination among the chemicals and waste Conventions support capacity building, knowledge transfer, enhanced awareness and efficiency, and improved implementation of the Conventions and of the Sustainable Development Goals.

Synergies also exist between the Basel, Rotterdam and Stockholm Conventions (BRS Conventions) and the Minamata Convention. Provisions under the Minamata Convention addressing the interim storage of mercury and mercury wastes refer to relevant guidelines and definitions developed under the Basel Convention. A number of decisions adopted by the COPs to the BRS Conventions also make specific reference to the Minamata Convention. For example, identical decisions taken by the BRS COPs at their 2017 meetings requested the BRS Secretariat "to continue to enhance cooperation and coordination with the interim secretariat of the Minamata Convention" (BRS Secretariat 2017). Accordingly, Parties to the Minamata Convention have requested the Secretariat to continue to cooperate and coordinate with the BRS Secretariat (Secretariat of the Minamata Convention on Mercury 2017).

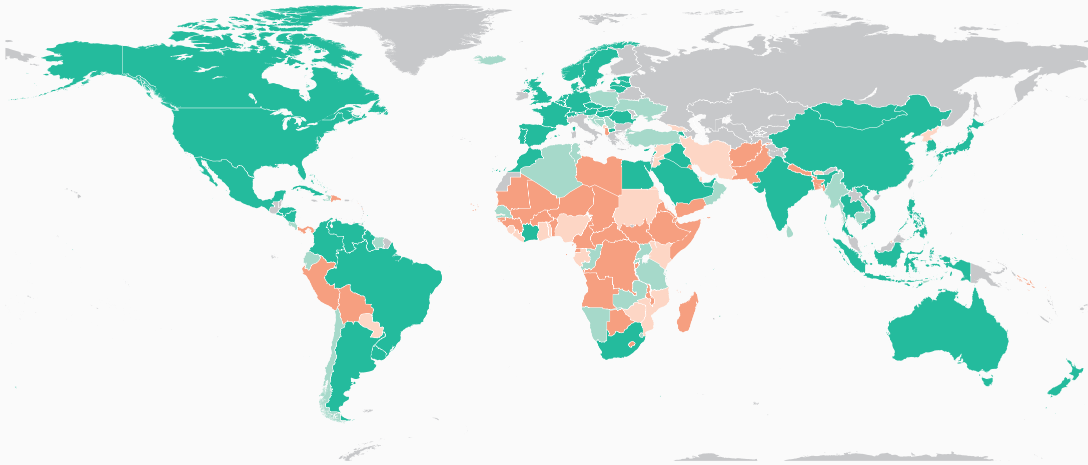
these NAPs (UNEP 2019a). The Convention also has provisions for phasing out the use of mercury in various products and ensuring the environmentally sound management of mercury wastes, among others. Since the Convention entered into force in 2017, it is too early to assess its effectiveness in a comprehensive manner.

### 3.1.6 ILO Conventions 170 and 174

ILO Convention 170 (the Chemicals Convention) was adopted in 1990, entered into force in 1993 and has 21 Parties; ILO Convention 174 (the Convention concerning the Prevention of Major Industrial Accidents) was adopted in 1993, entered into force in 1997 and has 18 Parties (see Part II, Ch. 1, 2). As mentioned in Part II, Ch. 2, the ILO has a structure of committees that oversee implementation of its Conventions.

In 2007 a Meeting of Experts to Examine Instruments, Knowledge, Advocacy, Technical Cooperation and International Collaboration as Tools with a view to Developing a Policy Framework for Hazardous Substances recommended that a plan of action be developed based on the following fundamental pillars: information and knowledge; preventive and protective systems aimed at the reduction of risks; capacity building; social dialogue; and good governance. This plan of action should be implemented using a variety of instruments, including ILO standards and joint actions, and be based on the principles of the 2003 Global Strategy on Occupational Safety and Health and SAICM, in partnership with workers, employers and governments (ILO 2007). Follow-up activities by the ILO have been summarized in the document *Safety and Health in the Use of Chemicals at Work* (ILO 2013).

**Figure 3.9** Countries with core capacities for chemicals under the International Health Regulations (2005), 2018 (adapted from WHO 2018a)




### 3.1.7 The WHO International Health Regulations (IHR) (2005)

The International Health Regulations (IHR) (2005) were adopted by the World Health Assembly in 2005, entered into force in 2007 and have 196 Parties (see Part II, Ch. 1 and 2). They require monitoring of the development and implementation of defined core public health capacities in order to detect, assess, notify and report events, and to respond to public health risks and emergencies of national and international concern. For example, core capacity 12 covers the detection and alerting of, and response to, chemical events (WHO 2018a). Other capacities include chemical events (e.g. emergencies) legislation and policies, preparedness and response, and strategic coordination.

The Global Health Observatory provides information on the status of implementation, which is indicated across four levels, with 59 countries (30 per cent) having achieved the highest level (75-100), 17 (9 per cent) scoring at the second level, 23 (12 per cent) at the third level and 27 (14 per cent) at the basic level. For 67 countries (35 per cent) there is a lack of data (WHO 2018a). Significant progress was made between 2010, when 38 countries had achieved core capacities for chemicals under the IHR, and 2016, when 60 countries had done so; however, a downward trend materialized by 2017, when only 56 countries had achieved these core capacities (IOMC 2019). Figure 3.9 provides an overview of the development of core capacities for chemicals under the IHR in 2016, illustrating the need for further efforts to achieve full implementation, particularly in the African region (WHO 2018a).

## 3.2 Progress in achieving the five objectives of the SAICM OPS

### 3.2.1 Governance

One of SAICM's objectives for "governance" is to "promote the sound management of chemicals within each relevant sector and integrated programmes for sound chemicals management across all sectors" (SAICM Secretariat, UNEP and WHO 2006). Strengthening of appropriate national, regional and international mechanisms, enforcement, relevant codes of conduct and other relevant objectives has, among others, been achieved via the international agreements discussed above. The section below provides additional illustrations of progress at the national and regional levels.


## Africa

In recent years, various countries in Africa have made progress in strengthening their chemicals and waste management capacities. For example, Kenya is in the process of putting in place the Environmental Management and Coordination (Toxic and Hazardous Chemicals and Materials Management) Regulations (Hazlewood 2019). Other recent legislative progress in the region has largely been restricted to adoption of legislation addressing specific chemicals, such as the national policy framework for the management of PCBs approved in Nigeria in 2015. Recent

**Table 3.2 Examples of regional institutions and initiatives addressing chemicals and waste in the African region**

| Institution/initiative | Examples of implementation bodies and activities |
|---|---|
| Southern African Development Community (SADC) | › Technical Regulations Liaisons Committee promote and facilitates implementation of the SADC Technical Regulation Framework<br>› SADC Policy on the GHS<br>› Development of the Code on Safe Use of Chemicals under the Employment and Labour Sector Programme |
| Economic Community of West African States (ECOWAS) | › Sahelian Pesticide Committee<br>› West African Committee for Pesticide Registration Harmonization of regulations for control of pesticides<br>› Harmonization of chemicals data requirements, test guidelines, risk assessment, registration procedures and risk reduction |
| East African Community (EAC) | › Development and harmonization of standards and regulations on pollution control and waste management (e.g. EAC Electronic Waste Management Framework and Management of Plastic and Plastic Waste Disposal) |

efforts in South Africa to adopt a comprehensive chemicals management law – with provisions for industrial chemicals registration and risk assessment, and seeking to streamline the responsibilities of various government entities – have not materialized to date (Stringer 2017).

In past years a number of African countries have enacted legislation addressing chemicals in products, such as restrictions on certain substances in cosmetics in Morocco (Morocco Ministry of Health n.d.) and Rwanda (Rwanda Ministry of Health 2016) and new toy safety standards in Egypt (European Commission [EC] 2018). As of 2018, 11 countries (Algeria, Burundi, Cameroon, Ethiopia, Kenya, Nigeria, Rwanda, South Sudan, Tanzania, Uganda and Zimbabwe) had legislation and statutes limiting lead in all decorative paints. Waste management continues to be a priority in the region. In 2016 Ghana passed an act to streamline and strengthen waste management and recycling systems, including through the establishment of a fund to provide finance for the management of electrical and electronic waste (Republic of Ghana 2016).

Africa has a dense network of regional political and economic integration organizations. Given often limited national capacities, organizations such as the Southern African Development Community (SADC), the East African Community (EAC) and the Economic Community of West African States (ECOWAS) play an important role in advancing action on the sound management of chemicals and waste, for example through facilitating implementation of the GHS and harmonizing pesticides management (Table 3.2).

## Asia and the Pacific

Important recent legislative developments in the Asia-Pacific region include China's 2013 landmark Five-Year Plan for Chemical Environmental Risk Prevention and Control, which established chemicals management principles and featured a list of 58 priority chemicals for risk prevention and control (Chemical Watch 2013a). In addition, in 2018 several ministries jointly issued a list of 22 priority chemicals which would be subject to risk management and control measures (Chemical Watch 2018a). In Japan the Chemical Substances Control Act, often referred to as the "Japanese Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)", was amended in 2009, modifying the approach used to a risk- rather than hazard-based one (Zaman 2016). The Act on the Registration and Evaluation of Chemicals (often referred to as "K-REACH") was adopted in the Republic of Korea in 2013 and entered into force in 2015, with an amendment entering into force in 2019 (Chemical Inspection and Regulation Service [CIRS] 2019).

**Table 3.3** Examples of regional institutions and initiatives addressing chemicals and waste in the Asia and the Pacific region

| Institution/initiative | Examples of implementation bodies and activities |
|---|---|
| Association of Southeast Asian Nations (ASEAN n.d.) | › Working Group on Chemicals and Waste (established in 2016)<br>› Establishment of the ASEAN-Japan Chemical Safety Database (launched in 2016) |
| South Asia Association for Regional Cooperation (SAARC) | › Development of regional standards for chemicals and chemical products<br>› Establishment of a network on waste management initiated via the Dhaka Declaration (2004) |
| Secretariat of the Pacific Regional Environment Programme | › Projects to strengthen legislative frameworks and waste management capacity |

In 2017 Viet Nam issued a Chemicals Decree specifying, among others, requirements for the production and trade of industrial chemicals and requiring classification in accordance with the GHS. The Decree features five lists of regulated chemicals (including lists of banned and restricted chemicals) (ChemSafetyPro 2017).

In India in 2017, the Ministry of Environment, Forests and Climate Change established an expert committee responsible for the formulation of the National Action Plan for Chemicals to address the issues of chemical control, management and pollution in India (Global Business Briefing 2017; Niadu 2017). Thailand is currently streamlining its hazardous substances lists and amending its Hazardous Substances Act, which regulates the import, production, marketing and possession of all hazardous chemicals used in Thailand (Chemical Watch 2013b; ChemSafetyPro 2016a). Regional cooperation on chemicals and waste management led by other organizations supports legislative and policy development in the region. The programme "Toward a Non-Toxic Environment in South-East Asia" has helped to develop a regulatory framework and institutional capacity in the countries of the Mekong region (Swedish Chemicals Agency [KEMI] 2016). Moreover, countries such as Malaysia and Thailand are aligning their policies with guidance provided by the OECD.

Economic and political integration organizations advancing regional cooperation on chemicals and waste management include the Association of Southeast Asian Nations (ASEAN) and the South Asia Association for Regional Cooperation (SAARC) (Figure 3.3). Countries in the Asia-Pacific region have also joined forces under the umbrella of intergovernmental organizations targeting specifically environmental matters. The South Asia Cooperative Environment Programme and the Secretariat of the Pacific Regional Environment Programme, for example, implement projects to strengthen capacities for environmentally sound management of waste and support the development of chemicals management legislation, among others. Another example for regional cooperation on chemicals and waste related issues is the developed a regional roadmap by the WHO South East Asia Regional Office (SEARO) to help Member States develop and implement national antimicrobial resistance (AMR) prevention and containment action plans.

## Europe

Chemicals legislation and policies are to a large extent jointly developed by Member States in the framework of the European Union (EU), most notably in the case of the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) Regulation. As REACH applies not only to chemicals produced in the EU but also to those imported, it has had significant economic and legislative effects beyond the Member States. In Central and Eastern Europe (CEE) Russia undertook a significant reform of its chemicals management system in 2016 by adopting a new technical regulation for chemical product safety, to come into force in 2021. It seeks, among others,

to improve the existing chemicals inventory, requesting notification procedures such as those stipulated in REACH for any new substances (ChemSafetyPro 2016b). The effect of the EU's legislative initiatives extends beyond its Member States. Accession candidate countries align their regulations with EU standards, as was recently done by Serbia (Chemical Watch 2018b). Similar developments can be observed in non-candidate countries (e.g. Ukraine) (Chemical Watch 2018c).

The EU is the key regional economic and political integration organization driving the development of a harmonized legal framework in Europe (Table 3.4). The most important and comprehensive legislation governing chemicals production and use in Europe is REACH, which entered into force in 2007 with three deadlines for registration of chemicals in the ensuing years, the last taking effect in 2018. The identification of substances of very high concern (SVHC) is an

**Table 3.4 Examples of regional institutions and initiatives addressing chemicals and waste in Europe**

| Institution/initiative | Examples of implementation bodies and activities |
|---|---|
| European Union (EU) | › European Chemicals Agency (ECHA)<br>› Development and implementation of joint chemicals and biocides regulations (e.g. REACH; Biocidal Products Regulation; Classification, Labelling and Packaging [CLP] Regulation) |
| Eurasian Economic Commission (EEC) | › Single registry of chemical materials and substances<br>› Adoption of a technical regulation on the safety of chemical products (2018) |
| Commonwealth of Independent States (CIS) | › Development of common standards for classification and labelling of chemicals and safety data sheets (SDS)<br>› Harmonization with the GHS<br>› Cooperation on e-waste management |


ongoing process. An SVHC Roadmap foresees having all currently known SVHC included in the Candidate List by 2020 (European Chemicals Agency [ECHA] n.d. a). Concerning the assessment and management of the risks of chemicals, REACH shifts responsibility from public authorities to industry. In Central and Eastern Europe the Eurasian Economic Union, the Eurasian Customs Union and the Commonwealth of Independent States are institutional umbrellas for the development of harmonized chemicals management frameworks (Table 3.4). Legislative initiatives on substance management in these associations are mainly aimed at implementing the GHS and managing risks arising from the handling of substances and materials.

### Latin America and the Caribbean

Several countries in this region have recently established overarching chemicals management policies, including Guatemala (2013), Honduras (2013), Ecuador (2015), Colombia (2016), Chile (2017) and Costa Rica (2017). Eight Caribbean

**Table 3.5** **Examples of regional institutions and initiatives addressing chemicals and waste in Latin America and the Caribbean**

| Institution/initiative | Examples of implementation bodies and activities |
|---|---|
| Southern Common Market (Sistema de Informacion Ambiental del Mercosur n.d.) | › Ad hoc Group on Environmental Management of Waste and Post-use Responsibility<br>› Ad hoc Group on Environmental Management of Chemical Substances and Products<br>› Action Plan on Chemical Substances and Products (2008); places priority on pesticides, mercury, management of contaminated sites, and implementation of the GHS |
| Andean Community of Nations (Comunidad Andina n.d.) | › Andean Law on the registration and control of chemical pesticides for agricultural use (created in 1998, modified in 2015)<br>› Action Plan for the Prevention and Response to Emergencies by Hazardous Chemical Products |
| Regional Intergovernmental Network on Chemicals and Waste | › Identification of regional priorities on chemicals and waste; first Action Plan for 2019-2020 |

countries (Antigua and Barbuda, Barbados, Belize, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago) are preparing a legal framework for chemicals management through a Global Environment Facility (GEF) funded project supported by the GEF and the Basel Convention Regional Centre for Training and Technology Transfer for the Caribbean Region (BCRC-Caribbean).

In addition, several countries have developed specific policies and programmes on industrial chemicals. Examples include the draft law on industrial chemicals in Brazil (scheduled to be submitted to Congress in 2018), whose intention, among others, is to establish a national chemicals inventory and to establish the process of registering, evaluating and controlling these chemicals (SAICM Secretariat 2018a). Countries in the region are also advancing in the implementation of the GHS, the implementation of PRTRs and the establishment of waste management capacity, including through promoting the concept of extended producer responsibility (e.g. in Argentina and Chile). A strong driver of chemicals management capacity in the region is countries' (imminent) membership in (Chile, Colombia and Mexico), interest in acceding to (Costa Rica) or collaboration with (e.g. Brazil, Jamaica) the OECD (OECD 2017).

Regional and sub-regional economic and political integration organizations such as the Southern Common Market and the Andean Community of Nations (Table 3.5) play an important role in advancing regulatory harmonization and the development and implementation of policy-oriented action plans on chemicals and waste. The Caribbean Community and the Central American Commission for Environment and Development are also actively addressing chemicals and waste issues. Free trade agreements with other regions and countries, such as the Caribbean Forum-EU Economic Partnership Agreement (Mclean and Khadan 2015), have further catalysed regulatory progress in regard to sound chemicals management. At the regional level, an important milestone accelerating implementation of the 2020 goal was the establishment of the Regional Intergovernmental Network on Chemicals and Waste in the context of the Forum of Ministers of Environment in 2016.

## North America

In the United States the Frank R. Lautenberg Chemical Safety for the 21st Century Act, in

**Table 3.6** Examples of regional institutions and initiatives addressing chemicals and waste in North America

| Institution/initiative | Examples of implementation bodies and activities |
| --- | --- |
| North American Agreement on Environmental Cooperation | › Commission for Environmental Cooperation supports cooperation to address environmental issues of continental concern |

force since 2016, amended the Toxic Substances Control Act. It regulates the introduction of new or already existing chemicals on the market in that country and authorizes the United States Environmental Protection Agency (US EPA) to evaluate potential risks from such chemicals, as well as to restrict their production and use accordingly. Among others, the Amendment requires the US EPA to evaluate the safety of existing chemicals in commerce, starting with those that may present unreasonable risk, and removes a requirement that the US EPA choose the "least burdensome" way to address the unreasonable risk posed by a chemical (United States Congress 2016).

Launched in 2006, the Chemicals Management Plan (CMP) is a Government of Canada initiative aimed at reducing the risks posed by chemicals to Canadians and their environment. The CMP builds on previous initiatives to protect human health and the environment by assessing chemicals used in Canada and by taking action on chemicals found to be harmful. The CMP is delivered jointly by Environment and Climate Change Canada and Health Canada through partnership and engagement with stakeholders. The CMP assesses environmental and human health risks posed by chemical substances, and develops and implements measures to prevent or manage those risks from a broad suite of risk management tools. The Canadian Government is taking action to set new directions and objectives for chemicals management. It has initiated a broad-based engagement with partners and stakeholders to inform the direction of chemicals management in Canada beyond 2020. This engagement will include consideration of many issues, including the approach to "substances of very high concern". The Government has also committed to introducing a bill to amend CEPA in a future parliament (Government of Canada 2018a).

The United States, Canada and numerous other countries are members of the OECD, which has been a critical driver for the development and application of harmonized methods and approaches for testing and assessment of chemicals, risk management, and chemical accident prevention, preparation and response, among others.

Established by the North American Agreement on Environmental Cooperation, the Commission for Environmental Cooperation supports cooperation among Canada, Mexico and the Unites States to address environmental issues of continental concern, including the environmental challenges and opportunities presented by the North American Free Trade Agreement. A Technical Working Group on Pesticides facilitates cost-effective pesticide regulation through harmonization (e.g. a registration system). In February 2011 the Governments of the United States and Canada launched the Canada-U.S. Regulatory Cooperation Council to facilitate closer cooperation between the two countries on the development of smarter and more effective approaches to regulation that strengthen the economy, enhance competitiveness, and protect public safety and welfare (Government of Canada 2017) (Table 3.6).

### West Asia

An example of an important recent legislative development with respect to the sound management of chemicals and waste in the West Asia Region is the Turkish Chemical Registration, Evaluation, Authorization and Restriction Regulations. These regulations are modelled

on the EU's REACH Regulation and will streamline several existing chemicals regulations (Chemical Watch 2017a). Turkey is also a member of the OECD. The Gulf Cooperation Council members – Bahrain, the United Arab Emirates, Kuwait, Oman, Qatar and Saudi Arabia – and Yemen recently initiated legislation to restrict the use of certain chemicals of concern in products such as electrical and electronic equipment (Hazlewood 2018), cosmetics and personal care products (Chemical Watch 2017b), toys (Chemical Watch 2013c) and detergents (Chemical Watch 2017c).

The Gulf Cooperation Council is an important vehicle driving the development of the harmonized legal chemicals management frameworks of its members (Table 3.7). Other entities active at the regional levels include the Regional Organization for Protection of the Marine Environment.

## Integrated national programmes, national profiles and institutional coordination

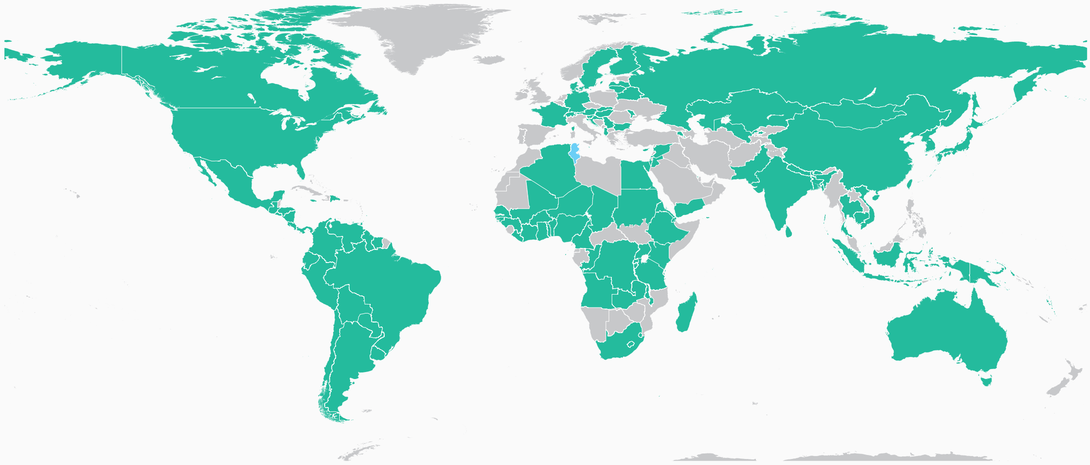
The development of country-driven and country-owned chemical management processes is among the topics prominently featured in the Overarching Policy Strategy of SAICM. Under governance, the OPS features as a specific objective promoting the development of "integrated programmes for the sound management of chemicals across all sectors".

Under the work area "Implementation of integrated national programmes" the GPA elaborates elements of such programmes

**Table 3.7 Examples of regional institutions and initiatives addressing chemicals and waste in the West Asia region**

| Institution/initiative | Examples of implementation bodies and activities |
|---|---|
| Gulf Cooperation Council | › Common System for the Management of Hazardous Chemicals (2002) established minimum legislation for the member states in dealing with hazardous chemicals<br>› "Green Gulf 2020 Project" implemented to help achieve the vision of an environmentally friendly Gulf by the year 2020 |

**Figure 3.10** National profiles to assess the chemicals and management infrastructure, 2018 (adapted from UNITAR 2018a)




including, among others, the development of a comprehensive national profile; formalizing inter-ministerial and multi-stakeholder coordination (including coordination of national government and multi-stakeholder positions in international meetings); and developing national chemical safety policies, outlining strategic goals and milestones towards reaching the 2020 goal agreed at the Johannesburg Summit in 2002. The specific indicator for this work reads as follows: "All countries have developed integrated national programmes for the sound management of chemicals within a five-year timeframe (2006-2010)".

## National profiles have fostered country-driven processes to strengthen chemicals management

The national profile concept, developed through collaboration of countries, stakeholders and IOMC participating organizations (with UNITAR in the lead), involves the development of a national baseline document concerning chemicals management through a process involving all concerned ministries and stakeholders. A national profile provides the status and identifies gaps in areas such as chemical legislation, institutional responsibilities and coordination, and information systems (UNITAR 2018a).

As of 2016, 116 countries had produced a national profile and many had developed a second or third edition. This represents a modest increase in numbers compared to the 106 countries in 2010 (IOMC 2019). The regional distribution of the preparation of national profiles in 2016, as compared to 2010, is as follows: Africa (39, up from 34), Asia-Pacific (23, up from 20), Central and Eastern Europe (CEE) (17, up from 16), Latin America and the Caribbean (LAC) (24, up from 23) and the Western European and Others Group (WEOG) (13, the same as in 2010) (Figure 3.10). The relatively small number of national profiles prepared or updated in the past years may be explained by the absence of stable funding. For example, the Quick Start Programme (QSP), which provided support for a number of countries to develop or update their national profile, does not exist anymore. The GPA had set a target/timeframe of 2006-2010 for the development of national profiles, which has thus not been met in many countries.

## Integrated national programme and SAICM Implementation Plans

In a number of countries the process of developing a has led to the establishment of formalized inter-ministerial coordinating committees, and fostered development of a programmatic and integrated approach to advance the sound management of

**Box 3.2 SAICM Implementation Plan for Guyana (Urho 2018)**

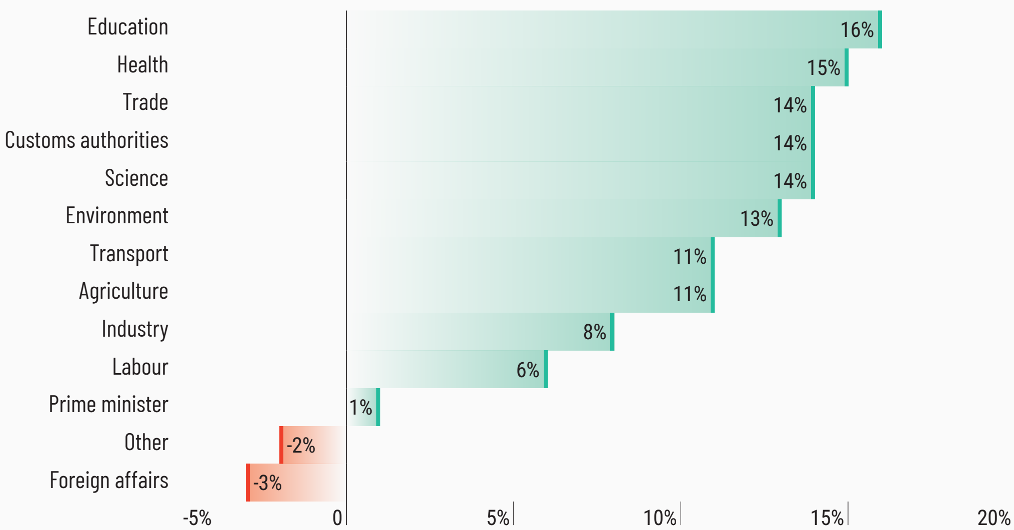
The SAICM implementation Plan for Guyana (2012-2015) aimed to strengthen national policies, programmes, networks and other mechanisms to ensure sound management of chemicals. The plan was based on a multi-sectoral approach involving all institutions, organizations and disciplines that took part in chemicals management in Guyana. It identified seven priority areas of work deriving from the GPA, including risk assessment, research and laboratory capacities, waste management, education and awareness-raising, stakeholder participation, prevention of illegal trafficking, and emergency planning. The Plan builds on valuable work done by the preceding QSP project on "Developing an Integrated National Programme for the Sound Management of Chemicals and SAICM Implementation in Guyana", which enabled, among others, the establishment of an inter-ministerial committee and the preparation of a national chemicals profile to take stock of existing national efforts and to prepare a national capacity assessment to identify priority work areas. Thus, through the implementation plan a logical continuum of prior work helped to establish necessary institutional capacities to deliver an action-oriented plan.

chemicals and waste (UNITAR 2004). National profiles have also served as a starting point in some countries for the development of action plans to support implementation of other international agreements. For example, national plans to support implementation of the Stockholm Convention were developed with funding from the GEF in more than 80 countries (Bengtsson 2010). Another spin-off has been the development of SAICM implementation plans, starting in 2009 with support from the QSP and based on guidance developed through collaboration of the SAICM Secretariat, UNITAR and IOMC (SAICM Secretariat 2009a). A case study on a SAICM Implementation Plan for Guyana (2012-2015) is described in Box 3.2. Urho (2018) discusses the implementation of this work area, but points out that a comprehensive analysis of integrated national programmes, national profiles and SAICM implementation plans is lacking.

### Sectoral engagement in national coordination mechanisms

The engagement of relevant sectors in national coordinating mechanisms encouraged through the OPS is monitored through SAICM indicator 11, which focuses specifically on education and health sector engagement. Figure 3.11 illustrates

**Figure 3.11 Engagement of sectors in coordination mechanisms, comparing results for 2009-2010 and 2011-2013 (adapted from SAICM Secretariat 2015a, p. 11)**



the trend for engagement of a wide range of key sectors in national coordination between the two reporting SAICM periods. Engagement of the education and health sectors increased by 16 and 15 per cent, respectively.

### 3.2.2 Knowledge and information

The SAICM objectives for "knowledge and information" include a range of measures. They emphasize, among others, the need "to ensure that knowledge and information on chemicals and chemicals management are sufficient to enable chemicals to be adequately assessed and managed through their life cycle". Action by governments and other stakeholders to achieve this objective (in addition to those already carried out under more specialized agreements) are briefly outlined below.

#### Chemical inventories have been established in a number of countries


A number of governments have made efforts to compile chemical inventories in order to obtain a better understanding of the number of chemicals on the market. Examples include the following:

- As of 2017, there were 140,000 chemical substances in the EU's CLP Inventory (ECHA 2017).
- The US EPA maintains an inventory covering about 85,000 chemicals sold in the United States (US EPA 2018a).
- When first published in 1994, the Canadian Domestic Substances List (DSL) contained some 23,000 substances manufactured in, imported into, or used in Canada on a commercial scale (Government of Canada 2018b). Substances have been added since its inception: there are now approximately 28,000 substances in the DSL.
- The Inventory of Existing Chemical Substances in China listed 45,612 substances in 2013 (ChemSafetyPro 2015).
- In 2018 Viet Nam launched the national chemicals database, which includes more than 170,000 substances (Kawanishi 2018).

#### Knowledge on chemicals in commerce is growing, but gaps remain

A report has been jointly developed by UNEP and the International Council of Chemical Associations (ICCA) to, among other purposes, improve the understanding of the number of chemicals in commerce (UNEP and ICCA 2019). The findings of this report include the following:

- There are an estimated 40,000 to 60,000 industrial chemicals in commerce globally.
- An estimated 6,000 of them account for more than 99 per cent of the total volume of chemicals in commerce globally.
- A number of factors contribute to uncertainty in estimates of the numbers of chemicals, including a lack of chemical inventories for many countries.
- Environmental, health and safety (EHS) data exist for the majority of the highest production volume chemicals, while knowledge gaps still exist for many lower-volume chemicals.
- There is a need for more and better chemical use and exposure information, particularly from developing countries, to improve risk assessment and risk management.

## Major initiatives have generated knowledge on the hazards of industrial chemicals

On chemicals applied for specific purposes (e.g. pharmaceuticals, pesticides and food additives) extensive hazard data are generally available. As discussed in section 3.1.2 above, the GHS is a harmonized system for classifying chemicals according to their potential hazards at the international level. National and international initiatives have generated a growing body of knowledge on the hazards of industrial chemicals.

- The OECD's High Production Volume Chemicals Programme, designed to challenge chemical manufacturers to assess the hazards of their chemicals, originally listed 5,235 chemicals and screened more than 1,200 before it was reformed into the Cooperative Chemicals Assessment Programme (OECD n.d.).
- Canada has addressed some 3,534 of the 4,300 chemicals it identified as priorities for action by 2020-21. The Government of Canada has found over 457 existing substances to be harmful to the environment and/or human health, and is now in the final phase of addressing these substances through its Chemicals Management Plan (Government of Canada 2018c).
- The EU's REACH and CLP requirements have generated large amounts of information on the health and environmental hazards of chemicals. In 2018 the ECHA reported receiving chemical dossiers from a total of 88,319 registrations, covering 21,551 unique substances under REACH. Of these, 2,575 chemicals were manufactured in (or imported into) the EU in quantities of over 1,000 tonnes per year (ECHA n.d. b).

## Many chemicals in commerce still have limited data sets and incomplete characterizations

Despite the substantial hazard data generated for thousands of chemicals, knowledge of chemical hazards, common exposure pathways, and human health and environmental effects for many chemicals is absent or insufficient. In a review of national efforts to implement chemical risk management actions, the OECD observed that "information gaps regarding the properties for many existing chemicals hampered risk assessment and management and subsequently, these chemicals may not have been appropriately risk managed" (OECD 2015). This analysis is consistent with studies in the past years pointing to data gaps in identifying human health and environmental hazards of many chemicals on the market (Grandjean *et al.* 2011; Egeghy *et al.* 2012; Strempel *et al.* 2012; Buonsante *et al.* 2014; Stieger *et al.* 2014; Bernhardt, Rosi and Gessner 2017).

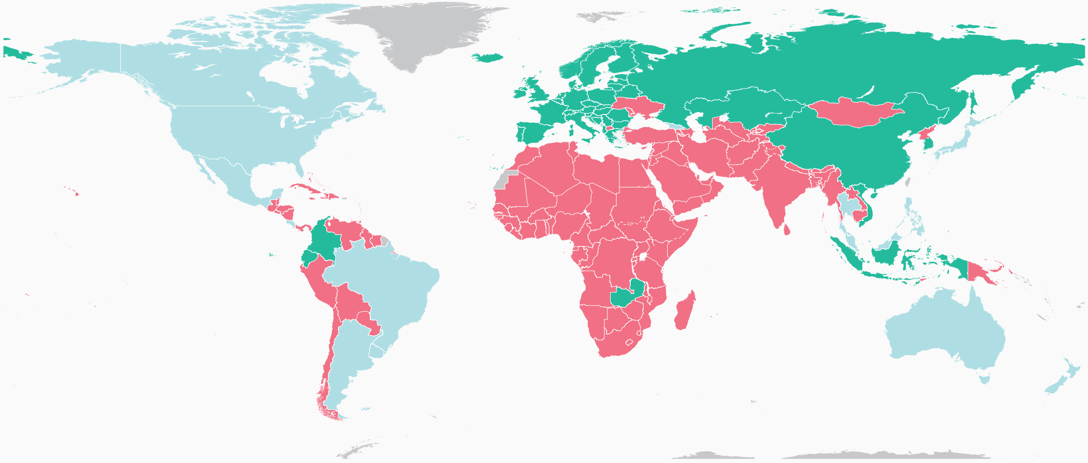
When the ECHA released its assessment of eight years of REACH implementation, it noted that "a significant proportion of registration dossiers are still not of a sufficient quality" (ECHA 2016). In 2017 the ECHA evaluation noted that 69 per cent of the dossiers received lacked complete hazard information. Of some 4,500 chemicals considered high priority by the ECHA, some 3,000 are considered to be in a "grey zone" where there is insufficient information to decide about the risks they pose (ECHA 2018). Recognizing this insufficiency of information, the OECD estimates that between 20,000 and 100,000 existing chemicals with historical approvals or notifications have not received a sufficient risk assessment or reassessment (OECD 2015).

## The Globally Harmonized System of Classification and Labelling of Chemicals

The GHS was adopted in 2002 and has been updated periodically since. GHS implementation was encouraged in paragraph 23c of the JPOI, with the objective of having this system fully operational by 2008 (UN 2002). The GHS was later included in the SAICM Overarching Policy Strategy (OPS), adopted in 2006. The Dubai Declaration and the SAICM OPS refer to the implementation of the GHS. It is one of the basic elements of the SAICM Overall Orientation and Guidance (OOG) adopted at ICCM 4 in 2015.

The GHS covers four sectors: transport, workplace (industrial), consumer and agricultural. Implementation of the GHS has three stages: formal adoption by countries; incorporation into national legislation; and facilitation and

**Figure 3.12** **Global GHS implementation status, 2018 (adapted and updated based on Persson *et al.* 2017, p. 8)**




enforcement of the uptake and use of GHS by companies and any other relevant actors. GHS implementation can be done using a "building block" approach, in which building blocks correspond to the different hazard classes and categories used to describe the nature of the hazards of hazardous substances/mixtures (UN 2005).

Figure 3.12 shows the global status of GHS implementation. To date, 51 countries have fully implemented the GHS and 16 have partially implemented it. While this shows progress compared to the total of 41 countries which had fully or partially implemented the GHS in 2010, 126 countries have not yet implemented it (updated based on Persson *et al.* 2017). Despite the long history of GHS implementation, there are significant disparities in implementation between developing and developed countries. Full legal GHS implementation is most common in Europe and parts of Central Asia, East Asia and Southeast Asia. In Latin America two countries, Ecuador and Colombia, have implemented the GHS fully; in Africa only Zambia and Mauritius have done so. The target established in the JPOI for full implementation of the GHS in all countries by 2008 has not been achieved in 2019. Persson *et al.* (2017) attributed insufficient progress to, among others, a lack of financial and regulatory

© UNITAR/Andrea Cararo, coal power plant in Ulaanbaatar capacities, as well as lower trade openness, in many countries.

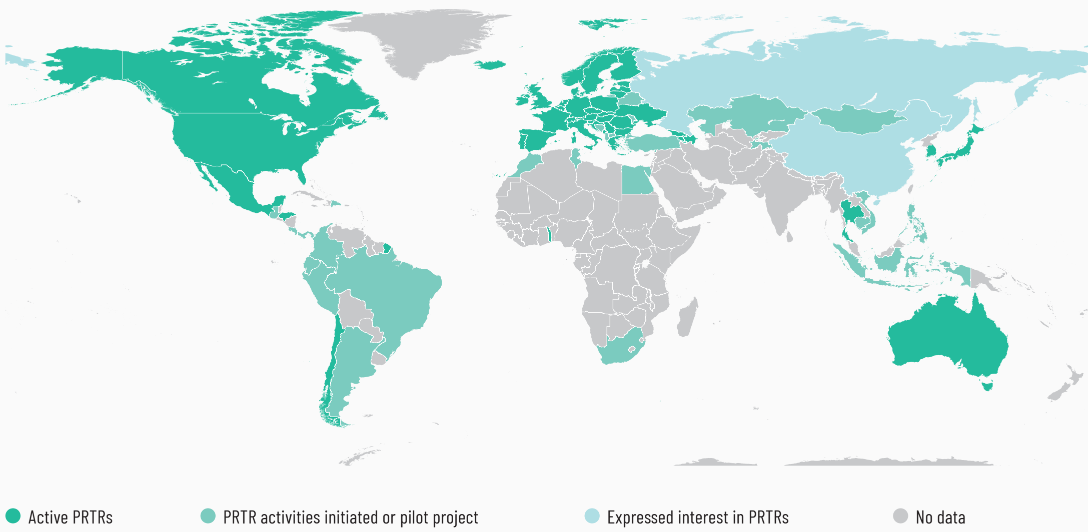
## Pollutant Release and Transfer Registers

A Pollutant Release and Transfer Register (PRTR) is a publicly accessible database, or multi-media inventory, of chemicals and pollutants released to air, water and soil and transferred off-site for treatment or final disposal. PRTRs bring together information, usually reported on an annual basis, about which chemicals are being released, where, how much and by whom. While the number of chemicals and the number of sources covered by a PRTR are limited, it is a useful basis for agencies and the public to compare releases from different sources and consider follow-up discussions with the releasing parties. PRTRs are not a tool for regulating emissions. However, the public information on point sources (e.g. of releases from industries) and diffuse sources (e.g. of releases from transport and agriculture) often helps create an incentive for companies to avoid being identified as major polluters and to voluntarily invest in making emission reductions.

The rationale for the establishment of PRTRs was established in 1992, when the importance of public access to information on environmental pollution, including emissions inventories, was recognized in Agenda 21 at the United Nations Conference on Environment and Development. Principle 10 states that "each individual shall have appropriate access to information concerning the environment that is held by public authorities" as well as "the opportunity to participate in decision making processes", and that countries shall "encourage public awareness and participation by making information widely available". Ten years later the Johannesburg Plan of Implementation called for action at all levels to "encourage development of coherent and integrated information on chemicals, such as through national pollutant release and transfer registers" (UN 2002).

Public access to information on chemical releases and transfers is a central PRTR characteristic, which contributes to achieving SDG 12.4 by helping to track progress concerning pollutant releases to air, water and soil. PRTRs have also been recognized as instruments for the collection and dissemination of information on estimates of the annual quantities of POPs (Article 10, Secretariat of the Stockholm Convention 2008). In 2017 the Minamata Convention on Mercury entered into force. Its Article 18 encourages Parties to promote and facilitate PRTRs as tools for the collection and dissemination of information on estimates of the annual quantities of mercury and mercury compounds that are emitted, released or disposed of through human activities.

**Figure 3.13** **Pollutant Release and Transfer Registers, 2018 (adapted from UNITAR 2018b)**






As of 2010, 35 countries had PRTRs in place; by 2016 this number had increased to 50. Significant gaps therefore still exist (IOMC 2019). In Europe and North America PRTRs are in place or are in the process of being established. Progress is also being made in the LAC region, although gaps remain. According to available data, in the Asia-Pacific region only Australia, Japan and the Republic of Korea have PRTRs, and in West Asia and Africa no country is known to have a PRTR in place. Interest in PRTRs exists in some countries, notably China and Russia. Figure 3.13 shows the global status of the development of PRTRs (UNITAR 2018b). The target set in the GPA for PRTRs to be established in all countries by 2015 has thus not been achieved.

### Environmental and health monitoring

"Monitoring and assessing the impacts of chemicals on health and the environment" is element 10 of the Overall Orientation and Guidance (OOG). The latest SAICM Progress Report found that there had been an increase in health and environmental monitoring since 2009. A number of parameters were used to measure this, including monitoring of chemical incidents, poisonings, human biomonitoring, occupational diseases and environmental monitoring systems. With respect to human health, the average increase was 5 per cent, a result similar to that obtained for environmental monitoring (SAICM Secretariat 2015a) (Figure 3.14).

### International bodies and initiatives working on science assessment to support policymaking

A number of international bodies and mechanisms that bring together scientists and policymakers have been established to ensure that policymaking is informed by the latest scientific evidence. A report prepared by the IOMC in 2018 gave examples of science policy bodies and mechanisms active in chemicals and waste issues (WHO *et al.* 2018). For example, the WHO has established a Chemical Risk Assessment Network. One of its objectives is to assist in the identification of emerging risks to human health from chemicals. Under the intersessional process to prepare recommendations regarding the

**Figure 3.14** **Progress in environmental and health monitoring, comparing results for 2009-2010 and 2011-2013 (adapted from SAICM Secretariat 2015a, p. 6)**

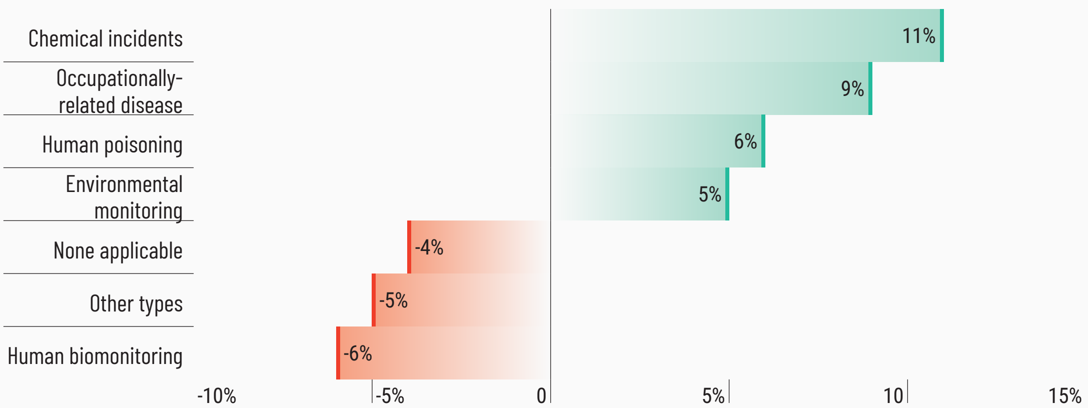


**Table 3.8 Examples of science policy bodies and mechanisms (based on WHO *et al.* 2018)**

| Body/initiative | Activities/scope |
|---|---|
| Persistent Organic Pollutants Review Committee (PORC) of the Stockholm Convention | Reviews Parties' proposals for listing new chemicals, decides whether a proposed chemical is likely to have POPs characteristics warranting global action, evaluates possible control measures taking into account socio-economic considerations, and makes recommendations for listing. |
| Basel Convention's Open-ended Working Group | Provides advice on issues relating to policy, technical, scientific, legal and other aspects of the implementation of the Convention; expert working groups develop guidelines on specific waste-related issues, e.g. e-waste, or to address other issues as mandated by the COP. |
| Rotterdam Convention's Chemical Review Committee | Reviews proposals for listing severely hazardous pesticide formulations. |
| Scientific Assessment Panel (SAP) of the Montreal Protocol | Assesses the status of the depletion of the ozone layer and relevant atmospheric science issues; any emerging scientific issues of importance are brought to the attention of the Parties. |
| FAO/WHO Codex Alimentarius Commission | Charged with protecting the health of consumers and ensuring fair practices in food trade through the development of a broad range of voluntary standards, guidelines and codes of practice under the Joint FAO/WHO Food Standards Programme. |
| FAO/WHO Joint Meeting on Pesticide Management (JMPM) | Advises countries on matters pertaining to pesticide regulation, management and use, and alerts them to new developments, problems or issues that otherwise merit attention. |
| WHO Chemical Risk Assessment Network | Aims to improve chemical risk management globally through facilitating sustainable interaction between institutions on chemical risk assessment issues and activities; decisions may lead to WHO guidelines, etc. |
| OECD Test Guidelines Programme | Development of internationally agreed testing methods used by governments, industry and independent laboratories to identify and characterize the potential hazards of chemicals. |
| Global Environment Facility´s Scientific and Technical Advisory Panel (GEF STAP) | Provides strategic scientific and technical advice on GEF policies, areas of work, projects, and programmes; builds networks with the science and policy communities of the Conventions which the GEF serves; brings to the GEF's attention priorities which may not be covered by the Conventions. |

Strategic Approach and the sound management of chemicals and waste beyond 2020, stakeholders have shown interest in addressing the topic of "science-policy interfaces", which was one of the agenda items during the second meeting on the intersessional process (WHO *et al.* 2018). Table 3.8 shows bodies and mechanisms working on science policy issues which are listed in the report. Some of these bodies play an important role in the identification and prioritization of chemicals and emerging issues. For example, the POPs Review Committee (POPRC) reviews and provides recommendations on the listing of new POPs.

The conclusions of the IOMC report include that a variety of fora already exist for the provision of scientific or technical advice on a wide range of issues, and that there is a great deal of scope within current organizational structures and mandates to create new committees or panels to cover a broad range of chemicals related aspects (WHO *et al.* 2018). The need for strengthened engagement by scientists and a stronger role for scientific research has been emphasized by various stakeholders (International Panel on Chemical Pollution 2018).

The IOMC report also includes reference to SAICM's ICCM, which brings together governments, IGOs, industry, NGOs and academia (WHO *et al.* 2018). Under SAICM, a process has been established to identify and call for appropriate action on emerging policy issues (SAICM Secretariat 2009b) through the ICCM. This has resulted in

© IISD/ENB (enb.iisd.org/ipbes/ipbes5/), 5th Session of the Plenary of the Intergovernmental Platform on Biodiversity and Ecosystem Services

**Box 3.3** **Potential considerations for the selection of future issues of global concern**

In defining possible future priorities related to specific issues or chemicals of concern at the international level, questions of potential relevance for consideration by stakeholders may include the following:

- Which methodologies could facilitate the identification of possible future priorities at the international level in a systematic manner (e.g. using information on health and environmental impacts and harm caused, and by drawing on information from risk assessments)?
- Could a possible science-policy interface have a role to play in determining future priorities?
- Should priorities be set for individual chemicals (or groups of chemicals)?
- Should they cover broader management issues?
- How could a nomination process be designed, including clear criteria?
- How would the role of science in identifying and agreeing on issues/priorities be organized?
- How can commitment by key actors to take action be mobilized?
- What are criteria for sunsetting the issues?

**Box 3.4** **Identified challenges in creating a coherent global knowledge base: lessons for strengthening the science-policy interface**

While a wealth of data, information and knowledge on chemical production, releases, concentrations and effects has been generated, the GCO-II has encountered challenges in collecting coherent data and knowledge, developing global baselines and identifying trends. Data gaps at national, regional and global level include: the number and volumes of hazardous chemicals already on the market and those newly entering it; complete data sets concerning the hazard potential; and environmental, health and safety data, in particular for many lower-volume chemicals. Knowledge is also limited regarding outdoor and indoor releases of chemicals both during production processes and from products; chemical exposures in varying contexts; concentrations of hazardous chemicals in environmental media; and the adverse impacts of chemicals, including costs of inaction and benefits of action.

Significant progress has already been made in some areas to harmonize data generation, for example in testing chemicals. Yet challenges remain in facilitating coherent data collection and availability across time and countries, particularly in developing countries. This makes the identification of baselines, trends, emerging issues, priorities and progress at the global level challenging. It also renders comparability across time and countries or regions difficult, for example for chemical releases and concentrations. Research is often undertaken using different protocols and methods, for example using different units of analysis, or in determining the effects of chemicals on human health and the environment and translating these effects into economic costs and benefits. Promising progress is being made in harmonizing biomonitoring across countries, and could be extended to other areas.

Various barriers pose challenges in improving the scientific basis for informed decision-making. For example, scientists are not necessarily given incentives for producing policy-relevant knowledge. Another potential challenge is that policymakers may have short windows of opportunity for scientific input while related research may require longer timeframes. Moreover, policymakers and scientists may use different language, suited to the respective target audiences. Insufficient communication may also result in scientists not being sufficiently informed of policy needs and vice versa (Hering *et al*. 2014; Agerstrand *et al*. 2017).

Further examining and addressing some of the challenges noted above may be relevant for future assessments related to the sound management of chemicals and waste. Related discussions could also feed into the ongoing discussions on the science-policy interface.

the identification of eight emerging policy issues (EPIs) and other issues of concern to date (see Part II, Ch. 4). The "Paper by the Co-Chairs of the intersessional process on the Strategic Approach to International Chemicals Management and the sound management of chemicals and waste beyond 2020" (prepared for the third meeting of the Open-ended Working Group of the ICCM) includes as a strategic objective that "issues of concern that warrant global action are identified, prioritized and addressed", noting in the considerations that "the intention is to cover topics similar in nature to those covered by the Strategic Approach, emerging policy issues and other issues of concern, as well as topics such as managing specific chemicals, the burden of disease and financing" (SAICM Secretariat 2019a).

### 3.2.3 Risk reduction

The SAICM objectives for "risk reduction" include the need to "minimize risks to human health, including that of workers, and to the environment throughout the life cycle of chemicals". Among others, stakeholders also aim "to implement transparent, comprehensive, efficient and effective risk management strategies" (SAICM Secretariat, UNEP and WHO 2006). Significant progress towards achieving this objective has been made via the international agreements on chemicals and waste discussed above. Further areas of progress are noted below.

#### Countries have prioritized chemicals for risk assessment and management

In addition to and often preceding international efforts to prioritize chemicals, a number of national and regional regulatory bodies have undertaken risk assessments and, subject to the results, undertaken risk management action for a number of identified priority chemicals. Many countries have regulations on the use of prioritized chemicals, including lead, cadmium, chromium, mercury and various highly hazardous pesticides. Major initiatives to prioritize chemicals for risk assessment and management include the following:

- The EU, under its REACH Regulation, had included as of February 2019, 197 chemicals on its "Candidate List of substances of very high concern for Authorisation". Special authorization for production or use is required for 43 chemicals (as of February 2019) and certain restriction conditions are in

place for 69 chemicals (ECHA n.d. c). The ECHA maintains a Community Rolling Action Plan that lists priority substances for evaluation by Member States. By March 2018 the list contained 108 chemicals (ECHA 2018).

- In 2017 the Chinese Ministry of Environmental Protection published the Prioritized List of Substances Subject to Control. The use of the substances included on the list (currently 22 entries) is subject to restrictions, and enterprises are encouraged to opt for safer alternatives (CIRS 2018).

- Based on a screening process examining combined hazard, exposure and persistence and bioaccumulation characteristics, the US EPA currently lists 90 chemicals/groups of chemicals in its Toxic Substances Control Action Work Plan. For selected chemicals/groups of chemicals (10 to date), the agency will conduct risk evaluations. Those conditions of use determined by the risk evaluation to present an unreasonable risk to health or the environment will move immediately into risk management, where restrictions will be imposed to eliminate such risk (US EPA 2018b).

- Through Categorization, the Government of Canada identified approximately 4,300 of the 23,000 chemical substances on its Domestic Substances List as meeting the criteria for further attention, and launched the Chemicals Management Plan (CMP) to address these priorities. Of the 4,300 substances, those that have been assessed and found to be toxic as per the Canadian Environmental Protection Act, 1999 (i.e., harmful to human health and/or the environment) have been further prioritized for development and implementation of risk management measures, such as regulations, pollution prevention planning notices, codes of practice and guidelines. Since the launch of the CMP in 2006, the Government of Canada has implemented over 90 risk management actions for existing chemicals (additional tools are in development) and received approximately 5900 notifications for new substances prior to their introduction on the Canadian market. These notifications have been assessed, and over 290 risk management actions have been taken to manage potential risks to human health or the environment. (Government of Canada 2018a)

### The International Code of Conduct on Pesticide Management

The first version of the Code of Conduct on Pesticide Management (see Part II, Ch. 1, 2) was adopted by the FAO Conference in 1985; the fourth version was approved by the Conference in 2013. The WHO adopted the Code in 2014 as its reference framework for international guidance on pesticide management. The guidelines on pesticide legislation are an important tool for operationalizing the Code of Conduct by helping to make necessary legislative changes (FAO and WHO 2014).

The FAO hosts FAO-LEX, an on-line repository of national legislation relevant to agriculture (FAO 2019). Almost all countries have implemented pesticide legislation in accordance with the WHO/FAO Code of Conduct. According to a global survey undertaken by the FAO in 2017, 173 FAO member countries had developed pesticide legislation based on the Code of Conduct while five had not yet done so (three from the African region and two from the LAC region). For 18 countries no data were available. Figure 3.15 shows countries that have pesticide legislation based on the Code of Conduct (FAO 2018). Progress in this area is promising, but significant further work is needed to fully implement best practices and minimize adverse effects from the use of pesticides, in particular highly hazardous pesticides, as further explored in Chapter 4.

### Asbestos

For a decade the Chemical Review Committee of the Rotterdam Convention has recommended listing chrysotile asbestos (the most common type of commercial asbestos) in Annex III of the Convention in order to make it subject to the Prior Informed Consent (PIC) procedure in international trade, but the COP has not yet agreed to this. Altogether 56 countries have enacted legislation to strictly ban all uses of asbestos, as shown in Figure 3.16. However,

**Figure 3.15** Countries with pesticide legislation, according to FAO data collected in the context of the Code of Conduct, February 2018 (adapted from FAO 2018)

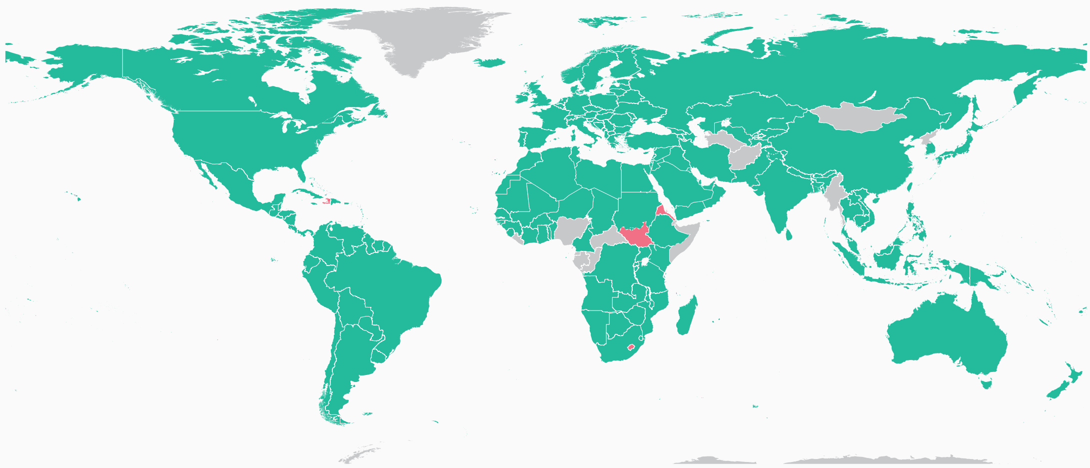
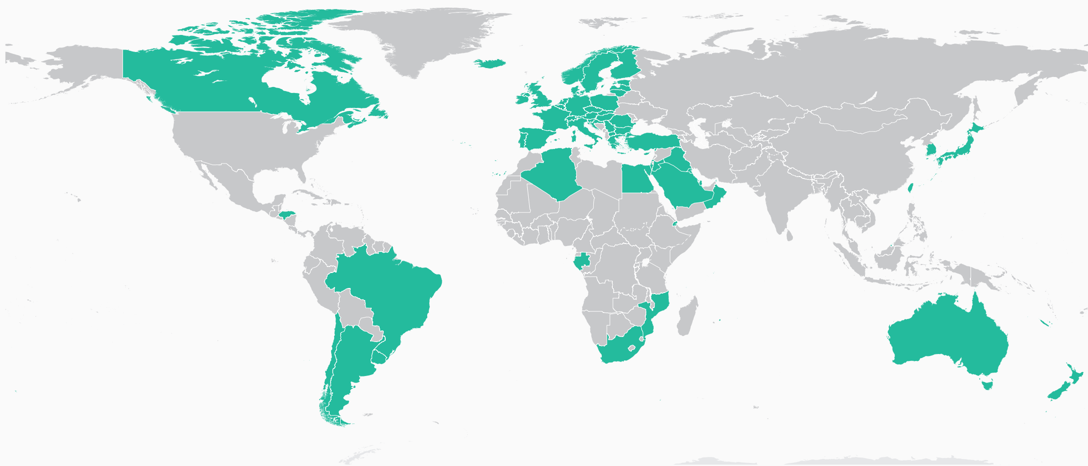
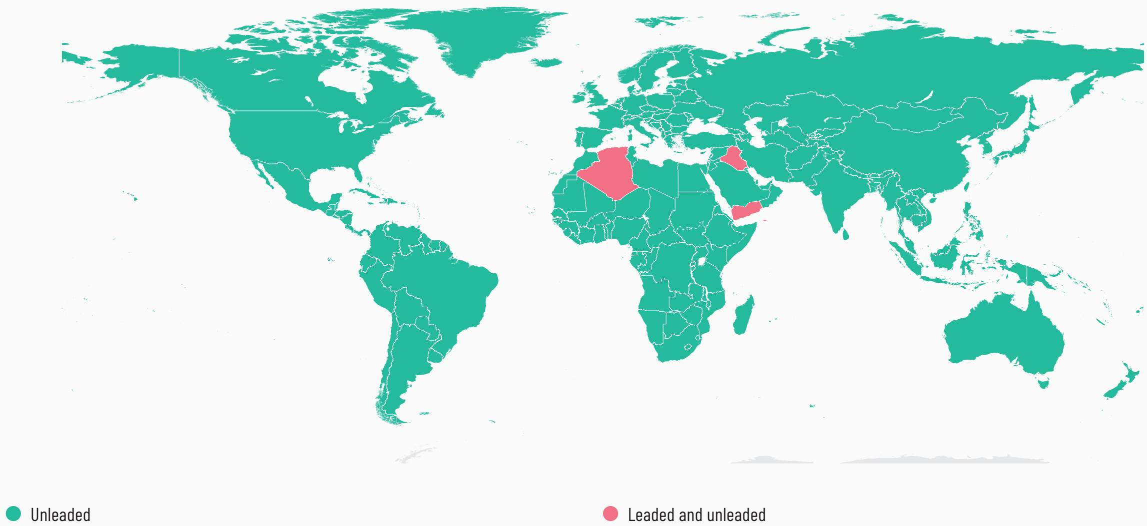



**Figure 3.16** Countries that have banned the use of asbestos, August 2018 (updated and adapted based on Kazan-Allen 2018)




© Mashava asbestos mine

**Figure 3.17** Global status of phasing out lead in gasoline, March 2017 (adapted from UNEP 2017, p. 1)

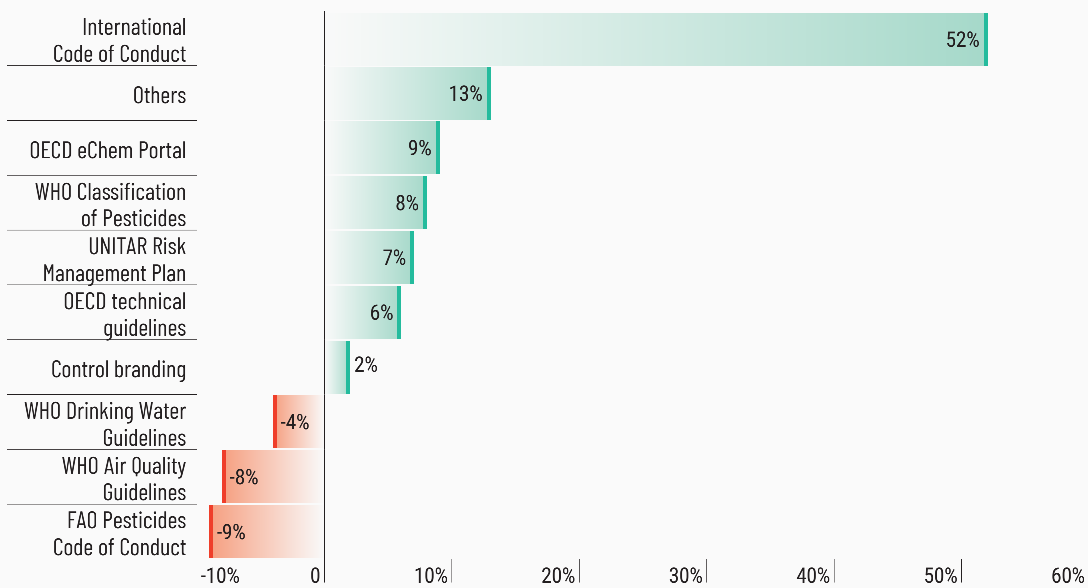



many countries outside Europe have not (yet) undertaken such action. Risk management of asbestos throughout its life cycle can be seen as contributing to OOG element 8.

## Lead in gasoline

In addition to regulatory action or bans, voluntary initiatives can be instrumental in achieving progress if they are taken seriously and tackled in innovative ways by all actors. While a number of countries took regulatory action to phase out lead in gasoline, UNEP worked with a Partnership for Clean Fuels and Vehicles, involving 120 civil society organizations, governments and major oil and vehicles companies, to support over 80 countries in the phase-out of lead in transport fuel (UN 2011). This can be seen to contribute to OOG element 8. This commitment is also reflected in many later documents, including SAICM's GPA. Progress has been steady and, as of March 2017, lead in gasoline had been phased out in almost all countries. While phasing out lead in gasoline can be considered a success story, it

**Figure 3.18** Trends the in use of IOMC tools for risk reduction for the reporting period 2011–2013 (adapted from SAICM Secretariat 2015a, p. 6)



also demonstrates that eliminating commonly used substances requires time and large-scale investment (UNEP 2017) (Figure 3.17). Progress in eliminating lead in decorative paint is explored in Chapter 4.

### Use of IOMC tools for risk reduction

Risk assessment and risk reduction through the use of best practices is reflected in OOG element 8. A number of IOMC organizations have developed guidance material which can be used by countries as tools for risk assessment and reduction. Some trends in the use of these tools are shown in Figure 3.9. In general, there is increased use of these tools, particularly concerning the International Code of Conduct on Pesticide Management. The tools shown in Figure 3.18, and many others, can be found in the IOMC Toolbox (OECD 2018a).

### Poisons centres

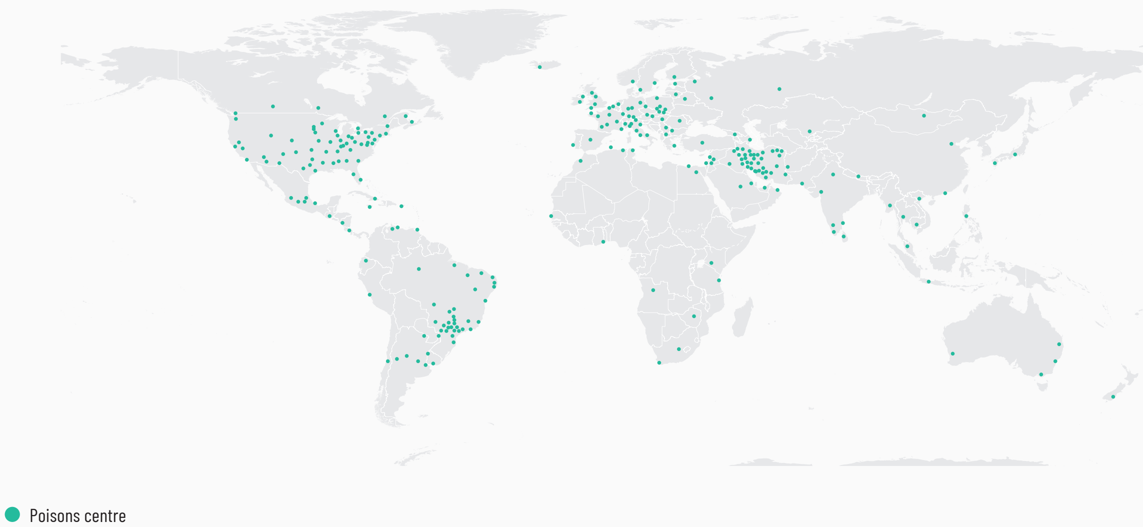
A poisons centre is a specialized unit that advises on, and assists with, the prevention, diagnosis and management of poisoning. The WHO has developed guidance and training materials on poisons centres and their operations and periodically organizes training workshops (WHO 2018b). Element 9 of the SAICM OOG calls for strengthening "capacities to deal with poisonings and other chemical incidents" by establishing poisons centres, which is also underlined in a number of GPA activities (SAICM Secretariat 2015b).

Figure 3.19 shows the global distribution of poisons centres as of September 2017. There has been limited progress in establishing these centres. Less than half of countries have a poisons centre, with the most notable gaps in the African, Eastern Mediterranean and Western Pacific regions (WHO 2017). While 91 countries had a poisons centre in 2010, only 90 countries had one in 2016, the only IOMC indicator for which a downward trend can be observed (IOMC 2019). The GPA target to have poisons centres established in all countries by 2010 has therefore not been achieved.

## 3.2.4 Capacity building and technical cooperation

SAICM's objectives of "capacity building and technical cooperation" include the need to increase the capacity for sound chemicals management, especially in developing countries and countries with economies in transition, through partnerships and mechanisms for technical cooperation, among others. SAICM is also to call upon existing and new sources of financial support to provide additional resources (SAICM Secretariat, UNEP and WHO 2006). The section below provides an indication of the

**Figure 3.19** **Existence and distribution of poisons centres, September 2017 (adapted from WHO 2017)**





progress made towards this objective, in addition to the capacity building and financial support provided through international agreements.

The SAICM Progress Report (SAICM Secretariat 2015a) found an increase of around 10 per cent in the number of middle-income countries reporting that their development assistance programmes included chemicals, and increases of up to almost 80 per cent and 60 per cent for lower- and upper middle-income countries, respectively, compared with the first SAICM Progress Report. Moreover, progress was noted in the provision of financial and technical resources: 57 per cent of countries reported the provision of bilateral financial assistance, compared with only 34 per cent in the first reporting period. Similar progress was observed in the provision of technical assistance. Yet the same report also found that, among the five objectives of the OPS, there had been least progress towards achieving capacity building and technical cooperation (SAICM Secretariat 2015a).

As an important element of capacity building, the integrated approach to financing sound management of chemicals and waste was adopted by the UNEP Governing Council in 2013 and welcomed by the UN Environment Assembly (UNEA) at its first session in 2014. This approach has three mutually reinforcing components to supplement and complement domestic resources mobilized by countries, in order to implement convention obligations and other commitments at the national and regional level: mainstreaming, industry involvement, and dedicated external finance.

### 3.4.2.1 Mainstreaming

Mainstreaming chemicals and waste occurs when governments, both recipients and donors, integrate sound management of chemicals and waste into their development plans and/or priorities. The overarching objective of mainstreaming is to align regulations, economic instruments and other policy instruments, with a view to correcting market failures and ensuring that the costs of environmental degradation are covered according to the polluter pays principle. Various activities have been implemented to support mainstreaming, including the UNEP and UNDP partnership initiative, which was found to have been successful in introducing the sound management of chemicals into development planning processes in some countries but less so in others (SAICM Secretariat 2015c). A number of countries which participated in the initiative succeeded in engaging new stakeholders, including in economic development sectors, finance and development planning (UNEP 2016).

The summary report on progress in the implementation of the Strategic Approach for the period 2011-2013 (SAICM Secretariat 2015a) found below-average levels of progress on mainstreaming chemicals into national development plans. The impact evaluation of the Quick Start Programme (Nurick and Touni 2015) found that in many cases QSP projects succeeded in "mainstreaming chemicals management" into national legislation, policies and institutions. However, in a few countries projects were followed up through resources allocated from national budgets/resources. The draft independent evaluation of the Strategic Approach from 2006-2015 (SAICM Secretariat 2018b) highlighted Zambia as a particularly successful example of mainstreaming chemicals and waste into national financing as a result of a QSP mainstreaming project. The Zambian Environment Management Authority retained fees raised through licensing of chemicals manufacture and registration, importation and export, and used them for monitoring and enforcement.

In reviewing existing projects, the UNEP *Report on the Implementation of the Integrated Approach to Financing the Sound Management of Chemicals and Waste* (UNEP 2016) identified a number of factors considered to be critical in further advancing mainstreaming, namely:

- align the chemicals mainstreaming activities with the policy cycle for national development planning processes;
- ensure high-level buy-in by government departments at the outset of activities;
- integrate the sound management of chemicals into chemical-intensive sector plans to ensure acceptance by the sector; and
- make advice and guidance on economic analysis available.

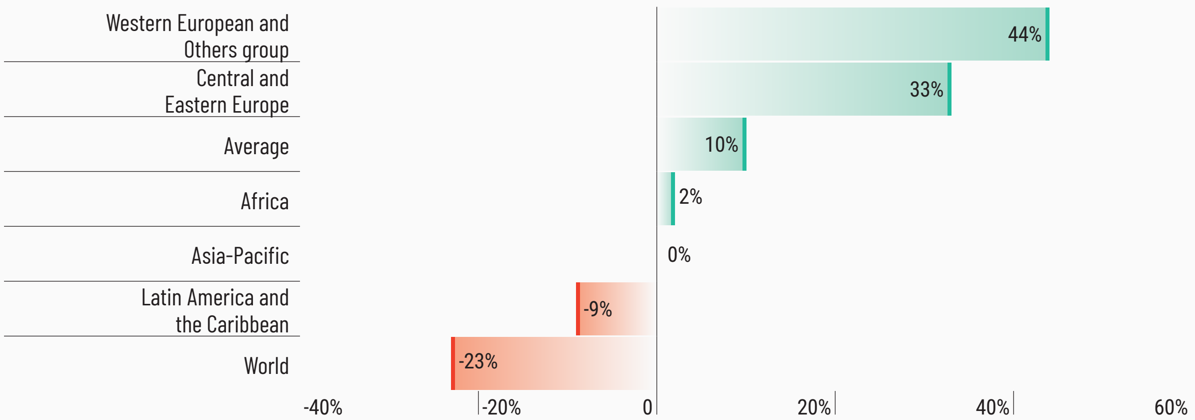
Given the limited progress in mobilizing financial resources in many countries, the report on *Financing the Sound Management of Chemicals and Waste beyond 2020* (SAICM Secretariat 2018c) recommends exploring a range of new opportunities including, among others:

- tapping into global sector funds related to sustainable development (e.g. those concerned with climate change or occupational safety);
- mobilizing philanthropic finance from private individuals, foundations and other organizations;
- exploring the potential of public pension funds and sovereign wealth funds;
- strengthening engagement of the financial sector and investors; and
- creating linkages with the implementation of the 2015 Addis Ababa Action Agenda of the Third International Conference on Financing for Development.

#### 3.2.4.2 Industry involvement

Industry involvement, in the context of the integrated approach, has been understood as referring to financial resources for the chemicals and waste agenda generated by the involvement of industry when, among others, industry internalizes the costs of complying with chemicals and waste regulations; economic instruments are used to recover and shift costs to the private from the public sector; industry transfers technology; industry pays taxes to governments; and industry takes innovative steps to "green" chemicals and waste throughout their life cycles. The private sector is an important driver of progress, for example in light of the importance of the significant resources it can mobilize. At different stages of the chemical life cycle relevant industries may have different roles to play in chemicals management, for example with respect to the application of the polluter pays principle and extended producer responsibility. As highlighted in a report on industry involvement, based on a consultative

**Figure 3.20** **Trends in private sector financial support comparing results for 2009-2010 and 2011-2013 (adapted from SAICM Secretariat 2015a, p. 13)**

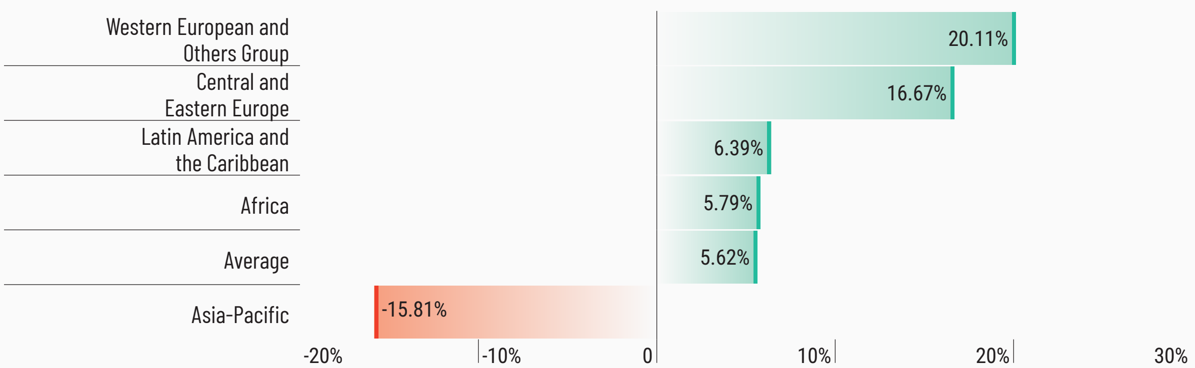



Note: World = IOMC and global organizations; Average = average for all regions and world categories of respondents

process facilitated by UNEP, "chemical producers have a specific responsibility" and "it is equally important to ensure that all others involved in the value chain recognize their responsibility and act accordingly" (SAICM Secretariat 2015d).

While a very small number of respondents reported accessing private sector finance in the first SAICM reporting period, a 10 per cent increase during the second reporting period represents a doubling of the total number; however, this was mainly driven by the Western European and Other States (SAICM Secretariat 2015a) (Figure 3.20). Stakeholders also reported that industry participation in multi-stakeholder committees increased on average by 6 per cent (SAICM Secretariat 2015a) (Figure 3.21). The consultative process facilitated by UNEP highlighted that chemical producers already contribute to the sound management of chemicals in various ways, including through testing of substances; development of exposure scenarios; development of Material Safety Data Sheets; meeting labelling and packaging requirements; sharing information with downstream users; and voluntary product stewardship initiatives. However, it also found "significant gaps in practice" regarding the contribution of producers (SAICM Secretariat 2015d). The process made a number of recommendations to advance industry involvement, including that governments adopt and implement legal instruments that

**Figure 3.21** **Trends in industry participation in multi-stakeholder committees comparing results for 2009-2010 and 2011-2013 (adapted from SAICM Secretariat 2015a, p. 13)**




Note: Average = average for all regions and world categories of respondents define responsibilities and that industry further incorporate sound chemicals management in corporate governance.

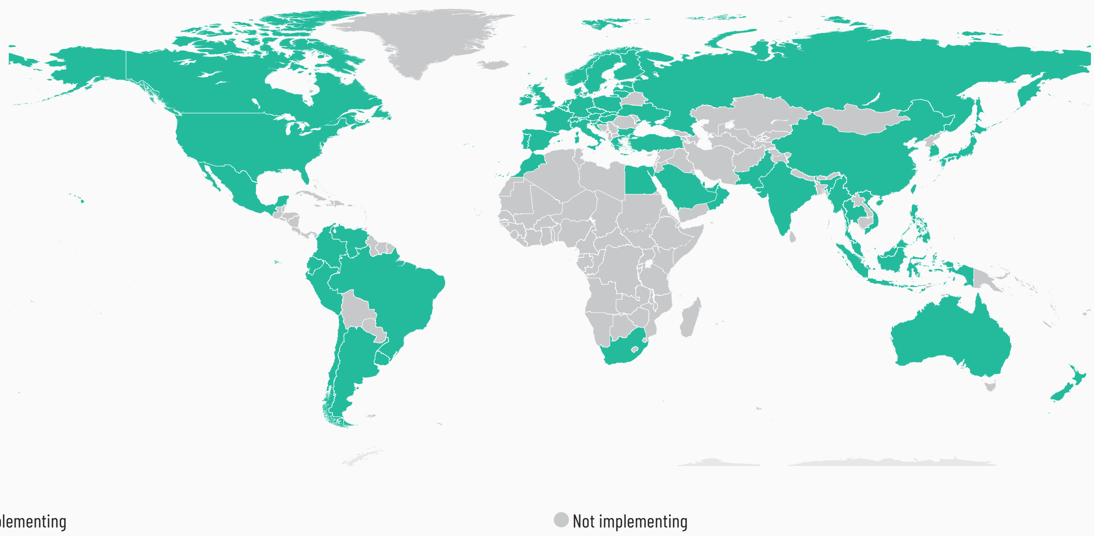
The Responsible Care® Global Charter is described as the backbone of the global chemical industry's voluntary Responsible Care® programme. It outlines nine key elements intended to enhance partners' health, safety, and environmental performance. The Global Charter has been signed in 68 countries by 580 companies, comprising 96 per cent of the largest chemical companies (ICCA 2015a) (Figure 3.22). However, there are significant regional variations in the implementation of the Responsible Care® programme. Gaps, especially in Africa and Latin America, are explained partly by the lack of major chemical company operations in many countries in these regions, and partly by the difficulty of engaging local and regional chemical companies in Responsible Care®. The target set in the GPA (SAICM Secretariat, UNEP and WHO 2006) for the implementation of Responsible Care® in all relevant countries by 2010 has thus not yet been fully achieved.

Industry is also involved in a number of activities related to chemicals and waste (including SAICM) at the international level, for example through partnerships such as those between UNEP and the ICCA and the Mobile Phone Partnership Initiative of the Secretariat of the BRS Conventions. The chemical industry has also contributed financial resources amounting to around US dollars 299,000 to the SAICM Secretariat (SAICM Secretariat 2018b). The Quick Start Programme impact evaluation (Nurick and Touni 2015) found industry involvement in QSP project coordination and delivery to be common if not universal, with provision of information constituting an important contribution by industry stakeholders. More substantive industry involvement has been achieved through projects with industry-relevant themes (e.g. GHS projects which involved importers, while Chemical Accident Prevention Plan projects involved users of chemicals). However, a very small minority of countries reported examples of the development and introduction of economic instruments to promote industry participation in financing for chemical management. Some limited examples of clarification of responsibilities are also described. In Nepal, for example, the introduction of a ban on lead in paint resulted in the establishment of private sector laboratories to meet the demand from the paint industry to test paints for lead concentrations (Nurick and Touni 2015).

### 3.4.2.3 External financing

External financing complements the components of mainstreaming and industry involvement through a financial mechanism to support recipient countries in implementing their legal

**Figure 3.22** **Countries with a chemical industry which have implemented the Responsible Care® programme as of March 2017 (adapted from ICCA 2019, p. 26 and 27)**



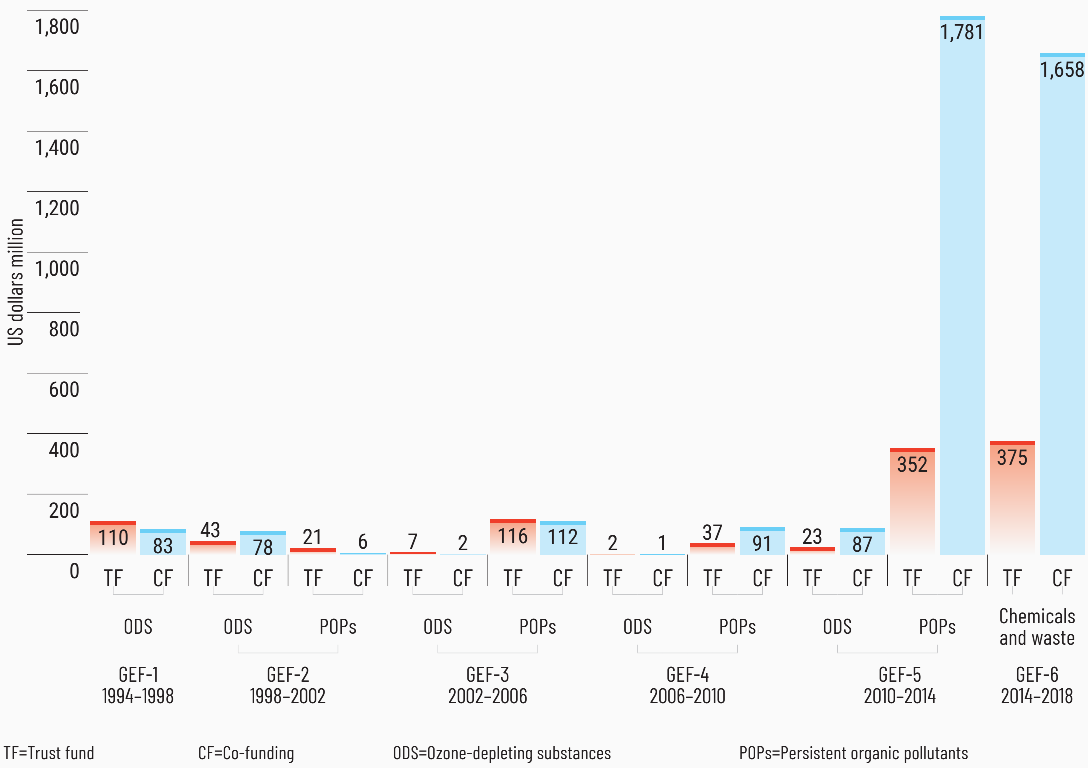
obligations and other commitments for the sound management of chemicals and waste. The external financing component of the integrated approach comprises the establishment of national chemicals and waste units in all recipient countries, as well as the creation of an integrated chemicals and waste focal area under the GEF, as established in GEF-5 (2010-2014). Strengthening sustainable chemistry technology innovation and financing is discussed in Part IV, Ch. 3.

### The Global Environment Facility

The Global Environment Facility (GEF) strategy to address chemicals and waste has changed significantly over time, and funding has increased substantially since its first Operational Strategy in 1995. At that time funding was restricted to action under the Montreal Protocol. In GEF-2 a dedicated programme for POPs was first introduced, as the GEF became an official funding mechanism under the Stockholm Convention. In GEF-4 separate focal areas for POPs and ODS were maintained, while support for sound chemicals management was made explicit for the first time through a cross-cutting strategic objective on sound chemicals management. Mercury was addressed to a limited extent by one of the strategic programmes under the International Waters focal area.

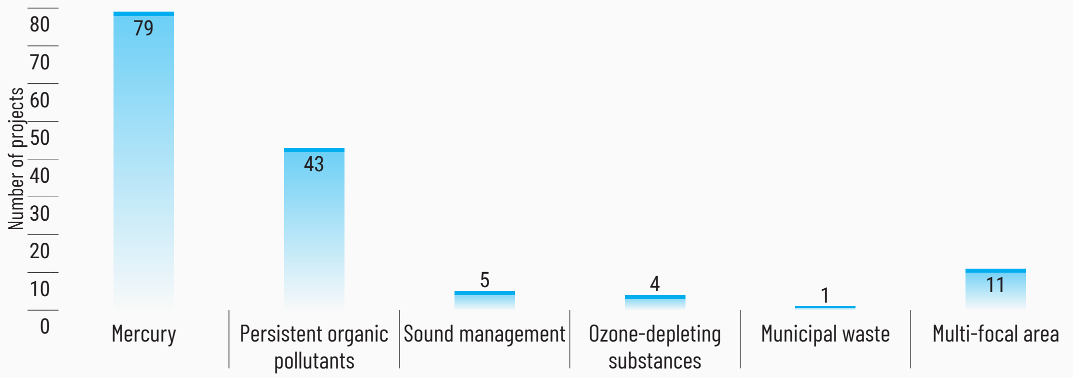
Subsequently, under GEF-5, a Chemicals Strategy offered a unifying framework to support the POPs and ODS focal areas, as well as for sound chemicals management and mercury (projects on sound management and mercury were

**Figure 3.23** Resource allocations for chemicals and waste by GEF round, 1994-2018 (based on GEF projects online database [GEF 2018])




The figure shows the total value/cost of all single-focal area projects (unless ODS and POPs are combined, in which case the project values were summed in the POPs focal area). For GEF 1-4 only the value/cost of completed projects are included in the calculation. The value/cost of cancelled projects and projects submitted to the GEF Secretariat but not (yet) approved were not included in any replenishment cycle.

**Figure 3.24** **GEF-6 projects by chemical group (based on GEF projects online database GEF 2018)**




Multi-focal area projects that include chemicals and waste among other focal areas have been counted. Excludes cancelled projects and projects submitted to the GEF Secretariat but not (yet) approved.

included in the POP Focal Area). GEF-5 (2010-2014) established an integrated chemicals and waste Focal Area under the GEF. For GEF-6 the GEF Assembly created a single Focal Area for chemicals and waste, replacing the POPs and ODS focal areas. The GEF-6 Strategy shows increased attention to mercury, covered under four of its six programmes, consistent with the progress in negotiations of the Minamata Convention (Figure 3.23) (Independent Evaluation Office of the Global Environment Facility 2018). Under GEF-7 chemicals and waste objectives can also be achieved through impact programmes, for example on sustainable cities.

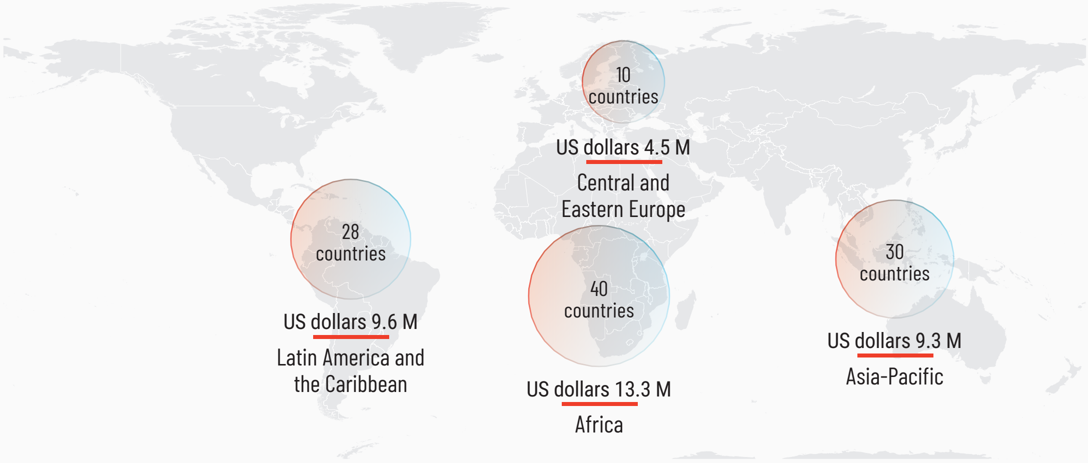
The programming targets for the chemicals and waste focal area under GEF-6 consisted of US dollars 554 million, compared to US dollars 425 million for GEF-5, to support implementation of the Stockholm Convention, the Minamata Convention, the Montreal Protocol and SAICM (in order of magnitude). This represents 12.5 per cent of total GEF-6 replenishment (GEF 2014) As of August 2018, US dollars 375 million was allocated to projects and almost US dollars 2 billion in co-financing was mobilized. The majority of direct funding was allocated for projects in Africa, while Asia mobilized the highest amount of co-financing. GEF-7 has an indicative allocation of US dollars 599 million, representing a slight increase compared to GEF-6, which is entirely for the Minamata Convention, while the other recipients from GEF-6 received less.

## The Quick Start Programme

The Quick Start Programme (QSP) was established in 2006 by the International Conference of Chemicals Management (ICCM) at its first session to support initial capacity building activities for the implementation of SAICM. Subject to certain conditions, civil society networks participating in SAICM are eligible for QSP projects.

From the date it was established to December 2017, the QSP mobilized over US dollars 47.6 million. This amount includes approximately US dollars 39.4 million in cash contributions to the QSP Trust Fund and over US dollars 9.7 million in cash and/or in-kind contributions from project implementers and Executing Agencies. The largest share of the projects was implemented in Africa, followed by Asia-Pacific and LAC (SAICM Secretariat 2018d) (Figure 3.25). The QSP impact evaluation (Nurick and Touni 2015), which reviewed 158 projects funded by the QSP Trust Fund as of October 2014, found the Trust Fund to be a unique funding stream. Many projects developed externally funded projects that effectively continued QSP projects (e.g. with funds from GEF, UN agencies, NGOs and donors). However, challenges were encountered in leveraging further resources. The QSP has been terminated.

**Figure 3.25** Overview of the Quick Start Programme since 2006 (adapted from SAICM Secretariat 2018d)




Total of 184 QSP projects in 108 countries.

### The Special Programme to Support Institutional Strengthening

The Special Programme to Support Institutional Strengthening supports country-driven institutional strengthening at the national level, in the context of an integrated approach to address the financing of the sound management of chemicals and waste (taking into account the national development strategies, plans and priorities of each country) to increase sustainable public institutional capacity for the sound management of chemicals and waste throughout their life cycle. Institutional strengthening under the Special Programme will facilitate and enable the implementation of the Basel, Rotterdam and Stockholm Conventions, the Minamata Convention and the Strategic Approach to International Chemicals Management (SAICM). Its terms of reference were adopted by the UNEA at its first session in 2014.

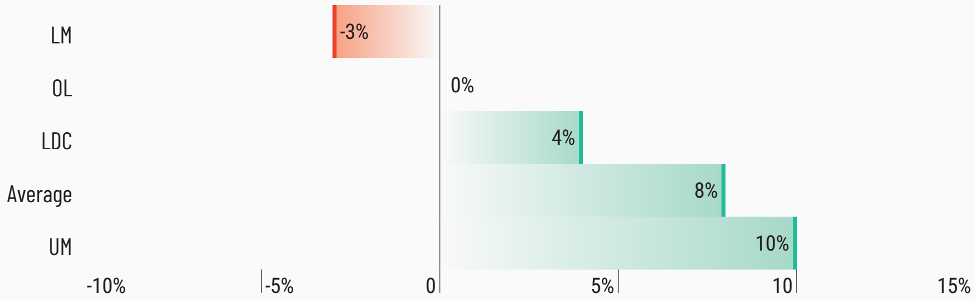
Support from the Special Programme is available for developing countries (taking into account the special needs of least developed countries and Small Island Developing States) and for countries with economies in transition, with priority given to those with least capacity. Eligible countries must be a Party to any one of the relevant conventions or have demonstrated that they are in the process of preparing for ratification of any one of the Conventions. Countries also have to identify the associated domestic measures to be taken, in order to ensure that the national institutional capacity supported by the Special Programme is sustainable in the long term. As of August 2018, the Special Programme had received contributions of US dollars 17 million. It has processed two rounds of applications and is currently funding projects in 24 countries in Africa, CEE, Asia-Pacific and LAC with a total budget of US dollars 6.85 million.

## 3.2.4.4 Other capacity development support

### International bodies

In line with their respective mandates, the nine IOMC participating organizations have made significant efforts to strengthen national and regional capacities for the environmentally sound management of chemicals and waste. A large number of projects have been implemented over the years, including technical assistance and guidance to reduce reliance on chemicals in agriculture; promotion of occupational health and safety; facilitation of environmentally sound disposal of POPs; and development of

**Figure 3.26** **Increase in percentage of developing country governments with development assistance programmes that address chemicals comparing results for 2009-2010 and 2011-2013 (adapted from SAICM Secretariat 2015a, p. 13)**




LDC: Least Developed Countries; LM: Lower Middle-income countries; OL: Other Low-income countries; UM: Upper Middle-income countries (DAC List of Official Development Assistance Recipients) (OECD 2018b); Average = average for all regions and world categories of respondents

inventories. An overview of the large number of activities on chemicals issues of the IOMC participating organizations in countries is compiled in a database (WHO 2018c).

An important contribution to support national capacity is the development of the IOMC Toolbox for decision-making in chemicals management. The internet-based Toolbox enables countries to identify the most relevant and efficient tools (e.g. guidelines, protocols and data sheets) to address specific national problems in chemicals management, covering among others a national management scheme for pesticides, an occupational health and safety system, and a chemical accident prevention, preparedness and response system. Since 2009 the IOMC participating organizations have also taken an active role in addressing the SAICM emerging policy issues, either leading or co-leading the activities. Moreover, these organizations have continued to provide assistance to countries, at their request, to implement the QSP project.

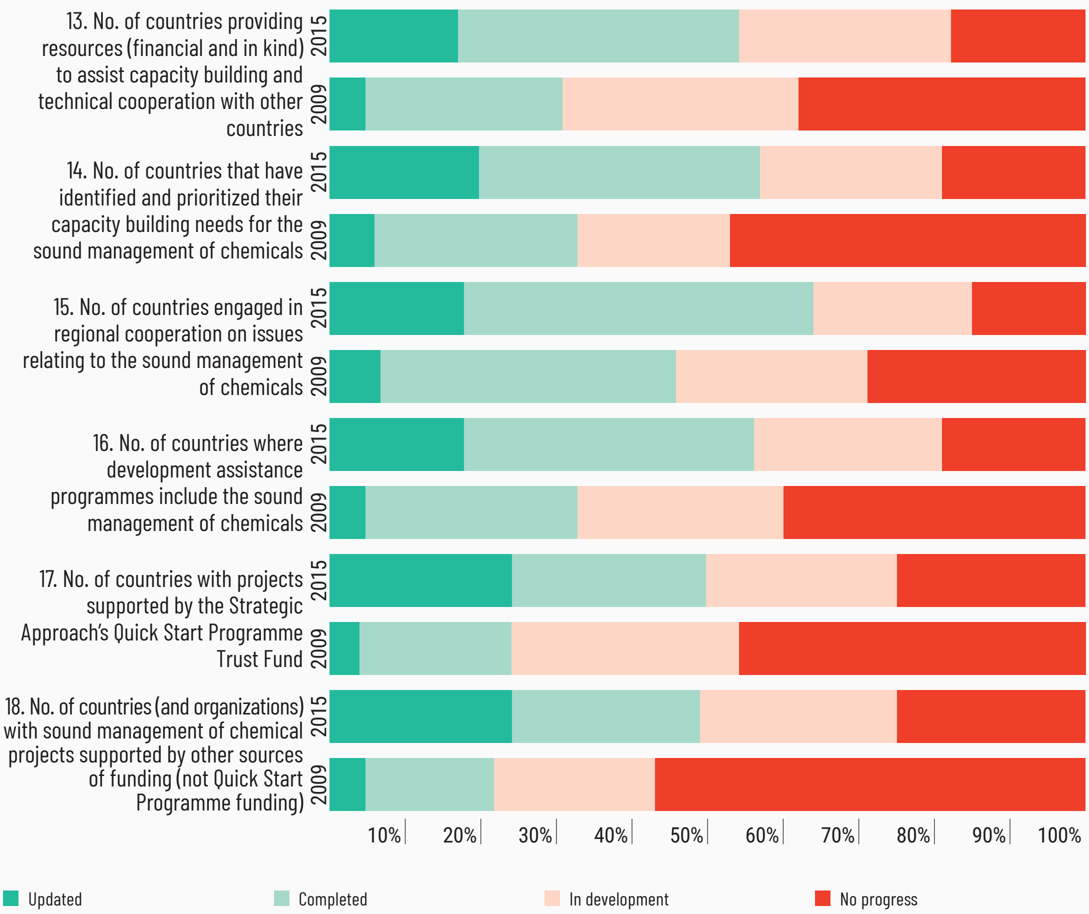
## Bilateral development assistance

A number of countries provide direct capacity-development support and technical assistance to facilitate sound chemicals management. For, example the Chemical Safety Convention Projects of the German Association for International Cooperation (GIZ) feature a number of projects in developing countries covering, for example, capacity building courses for SMEs on work safety and disposal of obsolete pesticides (GIZ 2014). Another example is the Swedish Chemicals Agency (KEMI) programme "Towards a Non-toxic South-East Asia", which aims to reduce health and environmental risks in several countries by, among others, strengthening capacity to innovate and scale up integrated pest management (KEMI 2016). Developing countries have also made progress in incorporating chemicals management in development assistance programmes (SAICM indicator 16) (SAICM Secretariat 2015a) (Figure 3.26).

## Civil society activities

A number of civil society organizations implement projects across the world, particularly in developing countries with limited capacity for the environmentally sound management of chemicals and waste. Examples include the International SAICM Implementation Project led by the International POPs Elimination Network (IPEN), under which more than 100 activities have been implemented in 50 countries to raise awareness, provide sectoral support, engage civil society in regulatory and institutional reforms, and build capacity for the sound management of chemicals and waste (IPEN 2018). Among numerous other initiatives facilitated by civil society organizations are those implemented by Health Care Without Harm and the Pesticide Action Network.

**Figure 3.27** **Comparison of results of the 2015 ICCA progress report with the 2009 baseline for SAICM indicators under capacity building and technical cooperation (adapted from ICCA 2015b, p. 7)**




## Private sector activities

In its fifth update report on implementation of SAICM, the ICCA (ICCA 2015b) highlighted the chemical industry's contribution to building capacity for the environmentally sound management of chemicals and waste through initiatives such as Responsible Care® and the Global Product Strategy. Reporting collected from its member associations indicated significant progress in advancing indicators under the OPS on capacity building and technical cooperation (Figure 3.27). Other examples include training farmers in developing countries in the responsible use of pesticides, facilitated by CropLife (CropLife International 2018a).

## 3.2.5 Illegal international traffic

**Despite progress made, including through the Basel Convention and the Rotterdam Convention, illegal international traffic remains on the international agenda**

Despite significant progress made in regulating the transboundary movement of chemicals and waste, including through the Basel Convention and the Rotterdam Convention, illegal international traffic remains a pressing global problem for many countries. Under the heading in the OPS "Illegal international traffic", SAICM aims to prevent illegal international traffic in toxic, hazardous, banned and severely restricted chemicals, including products incorporating these chemicals, mixtures and compounds and wastes (SAICM Secretariat, UNEP and WHO 2006). In 2018 participants in the sixth SAICM Africa


© Lisa Rivali/Shutterstock

Regional Meeting emphasized the importance of stopping illegal traffic, as well as the dumping of chemicals and waste, in Africa (SAICM Secretariat 2018e). The need for more work to address illegal trafficking of chemicals and waste across countries was also highlighted at the fifth SAICM Asia-Pacific Regional Meeting (SAICM Secretariat 2018f) and the sixth SAICM CEE Regional Meeting (SAICM Secretariat 2018g). However, data and information on illegal international traffic of chemicals and waste is scarce. This gap is to be addressed in a project led by UN Environment and GRID-Arendal.

### Illegal trade in products, pesticides and production processes poses diverse challenges

An important issue receiving the attention of policymakers is the import of products (e.g. cosmetics, toys, jewellery) that may contain banned substances (Chemical Watch 2018d). High concentrations of heavy metals in toys are regularly reported (Environment and Social Development Organization 2013; Ismail *et al.* 2017; Venugopal and Bose 2018). However, capacities for authorities to detect chemical concentrations in consumer products are often limited. Further examples of products containing illegal contaminants are skin lightening creams and soaps. Another emerging topic is the trade of low-quality fuels and fake fuels – products that contain substances in addition to or different from what an authorized seller represents (UNEP 2019b).

The rapid growth of the agriculture industry has led to intensive production and use of pesticides, including illegal pesticides. Trade in fake, obsolete and banned chemicals is taking place in illicit and licit markets. The identification and interception of illegal pesticides, however, is complicated by the vast number of chemicals on the market, low human and physical capacities to inspect shipments, and low awareness about the share of illegal trade. In some countries inadequate and unclear government enforcement responsibilities encourage non-compliance. Furthermore, new challenges emerge with e-commerce.

Some examples reveal that illegal trade of pesticides can be rather high. For instance, Europol conducted a series of three enforcement actions against the illegal trade in chemicals, the latest of which seized 360 tonnes of illegal pesticides including counterfeit pesticides (Europol 2018). Recent EU reports estimate that 14 per cent of pesticides sold in Europe are counterfeit and illegal, causing losses in revenue for the legitimate industry at around euros 1.3 billion annually (European Union Intellectual Property Office 2017; Europol 2018). Another study from India indicates that about 30 per cent of the volume of the domestic pesticide industry was illegal in 2013 (Agarwal and Garg 2015).

Illegal trade is also a challenge in production processes. For example, data available through the Artisanal Gold Council and the United Nations international trade statistics database (United Nations Comtrade 2018) suggest that about half of all mercury used in artisanal and small-scale gold mining (ASGM) is traded illegally or informally.

### Initiatives are in place at the global and regional level

Addressing illegal international traffic requires the existence of adequate legislative frameworks and their enforcement, both of which continue to present challenges in many countries including, but not exclusively, developing countries. Efforts and initiatives are under way in many countries to adopt new regulations and strengthen capacities for the control of transboundary movements. SAICM stakeholders have reported significant progress in monitoring traffic; implementation of national legislation preventing traffic; and training border control authorities, among others (SAICM Secretariat 2015a).

A number of governments are scaling up monitoring and control measures for imported products, but such activities still remain very limited. For example, KEMI regularly inspects companies importing products to verify that they are in compliance with existing legislative requirements (KEMI 2017a). It has implemented enforcement projects targeting, among others, trade in products exceeding allowable concentrations (KEMI 2017b). In the context of the Montreal Protocol, a global award has been launched to recognize the critical role of customs and enforcement officers in implementing trade restrictions and bans on HCFCs and HFCs (UNEP 2018b).

At the international level, the Rotterdam Convention is a key instrument providing an international framework to address international trade in certain hazardous chemicals and pesticides. The Convention's PIC procedure aims to ensure compliance of exporting Parties with the decisions of importing Parties as to whether they wish to receive future shipments of chemicals listed in Annex III of the Convention. With respect to the waste dimension of illegal international traffic, the Parties to the Basel Convention adopt decisions providing policy guidance to the Parties on how to prevent and combat illegal traffic. For example, Parties are encouraged to exchange information on their legislation or best practices and to transmit to the Secretariat forms for confirmed cases of illegal traffic. Parties also develop and adopt guidelines on how to prevent and combat illegal traffic. A number of initiatives, soft laws and policy frameworks foster cooperation between and within regions, building the capacities of law enforcers and providing additional knowledge tools, among other activities. Examples include the Green Customs Initiative, coordinated by UNEP, and the Environmental Network for Optimizing Regulatory Compliance on illegal Traffic (ENFORCE) coordinated by the Secretariat of the Basel Convention.

### Large amounts of illegal waste are seized by authorities

Awareness and knowledge of the trade of hazardous waste and other wastes between countries with different economies are growing. In 2017 the International Criminal Police Organization (INTERPOL) coordinated a global enforcement initiative to combat illegal transboundary movement of chemicals and waste. As a result of this operation, over 1.5 million tonnes of illicit waste were detected (INTERPOL 2017a; INTERPOL 2017b). The European Network for the Implementation and Enforcement of Environmental Law (IMPEL) regularly conducts coordinated regional inspections to implement the waste shipment regulation. The results of the latest project revealed that 16 per cent of waste-related shipments violated waste shipment regulations (Olley, Ross and O'Shea 2016).

In 2013 a joint operation across Europe and the Asia-Pacific region, Demeter III, was initiated by China Customs and organized by the World Customs Organization (WCO) to target mainly illicit maritime consignments of hazardous and other wastes. The operation netted more than 7,000 tonnes of illegal waste, including hazardous waste and e-waste (WCO 2014).

### Action is also taken in the private sector

A number of initiatives taken by, or in cooperation with, the private sector seek to address international illegal traffic. The US EPA has taken a positive step by working out an agreement with one of the largest online retailers to combat illegal trade in pesticides on the basis of inspections and monitoring evidence (US EPA 2018c). A private sector initiative, China Checkup, has attempted to warn customers about fraudulent suppliers on the platform of another major online retailer (Slater 2015). As regards pesticides, CropLife is engaged in anti-counterfeiting activities and works with relevant authorities to ensure that only authentic crop protection products are traded and that they

**Table 3.9** Stakeholder perceptions of the degree of success regarding prevention of illegal international traffic in chemicals and waste from 2006-2015, asked between 14 November 2016 to 4 January 2017 (SAICM Secretariat 2018b, p. 31)

| Stakeholder group | Very successful (%) | Some success (%) | Little success (%) | Unsuccessful (%) | Don't know (%) |
|---|---|---|---|---|---|
| Africa | 19 | 43 | 10 | 24 | 5 |
| Asia-Pacific | 0 | 25 | 50 | 0 | 25 |
| Central and Eastern Europe | 14 | 14 | 29 | 14 | 29 |
| Latin American and Caribbean | 0 | 30 | 22 | 4 | 43 |
| EU/JUSSCANNZ | 6 | 38 | 13 | 19 | 25 |
| UN agencies | 0 | 0 | 20 | 20 | 60 |
| Civil society | 12 | 12 | 12 | 35 | 29 |
| Industry | 7 | 36 | 21 | 7 | 29 |

JUSSCANNZ: Japan, US, Switzerland, Canada, Australia, Norway, New Zealand and other non-EU countries.

are used in a safe, responsible manner (CropLife International 2018b).

## SAICM stakeholders report progress in addressing illegal international traffic

According to the Draft Report of the Independent Evaluation of the Strategic Approach from 2006-2015 (SAICM Secretariat 2018b), 52 per cent of SAICM stakeholders consider that with respect to illegal international traffic (one of the five objectives of the SAICM OPS) some measure of success (very successful, some, little) has been achieved, while 49 per cent do not see a clear measure of success (unsuccessful, don't know). Comparing this to the average of opinions on the four other objectives (86 per cent found there was a measure of success, while 14 per cent did not), it is obvious that this OPS objective has been the most challenging and needs more

© Basel Convention Regional Centre for Asia and the Pacific effort. Opinions on success in the prevention of illegal international traffic among the various stakeholder groups is presented in Table 3.9. Particularly in the Latin American and Caribbean region, in civil society and within the UN agencies, there has clearly been a perception of success (SAICM Secretariat 2018b).

#### Challenges remain, among others due to differences in regulatory frameworks

National legislation regarding the legality of trade in chemicals differs significantly from jurisdiction to jurisdiction. The Basel Convention allows Parties to define certain wastes as hazardous beyond those listed by the Convention; hence the exact scope of the Convention differs from one country to another, with the consequence that some wastes are legally defined as hazardous in one jurisdiction but not in another. Similarly, maximum residue levels of pesticides are not uniform despite attempts to adopt global standards through the Codex Alimentarius. Food products banned in one country may still be permitted entry in countries that allow higher levels of hazardous substances. Adding to these complexities, existing multilateral treaties allow for certain exemptions and many chemicals that are traded internationally fall outside the scope of multilateral treaties.

#### Avoiding loopholes: the Ban Amendment and the Bamako Convention

Despite significant progress in international governance, the consequences of illegal international traffic of waste and chemicals are still a burden on human health and the environment. A topic of particular relevance is the distinction between products and waste, which is often not straightforward but highly relevant, as different regulations apply. In many cases hazardous wastes are relabelled and replaced on the market. Hazardous waste, particularly electrical and electronic waste, is frequently falsely declared as second-hand goods for recycling in order to circumvent existing regulations prohibiting the export of hazardous waste to a number of developing countries (Lipman 2015; Garlapati 2016). Obsolete pesticides are also reported to return back to the markets (UNEP 2019b).

Ninety-five countries have ratified the Basel Ban Amendment, which would ban transboundary shipments of hazardous wastes for any reason, including recycling, from the Member States of the EU and the OECD, and from Liechtenstein, to other Parties. However, the Amendment will only enter into force on the 90th day after receipt of the instrument of ratification, approval, formal confirmation or acceptance by at least three-fourths (66) of the 87 Parties at the time the Amendment was adopted in 1995, which has not yet occurred. In addition, the majority of African countries have ratified the Bamako Convention, which prohibits the import of any hazardous waste and which entered into force in 1998.

### 3.2.6 Additional insights from SAICM stakeholder reporting

Stakeholder reporting on SAICM implementation, as well as the independent evaluation of SAICM, provide additional insights relevant for assessing progress towards the achievement of the 2020 goal. Information gathered via these mechanisms is primarily derived from stakeholder perceptions of progress made in advancing activities relevant for the five objectives of the OPS. It can thus provide additional, although limited, knowledge and complement the analysis of initiatives and actions described in the preceding sections.

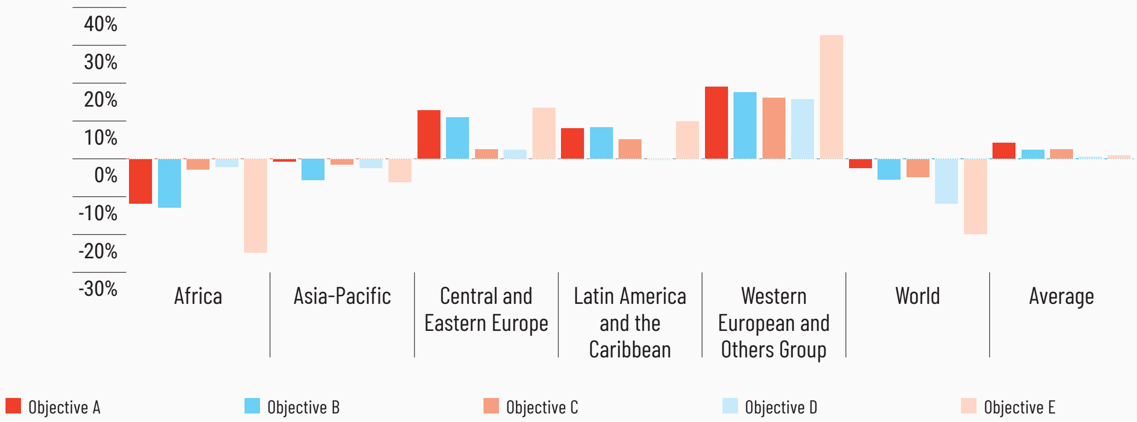
#### Stakeholder perceptions of progress under SAICM

SAICM was adopted in 2006 at ICCM 1 in Dubai. As stipulated in paragraph 24 of the OPS, the ICCM undertakes a periodic review of SAICM based on reports from stakeholders. A baseline estimates report, covering the period 2006-2008, was prepared in 2011 (SAICM Secretariat 2011). Three progress reports, for 2009-2010 (SAICM Secretariat 2012), 2011-2013 (SAICM Secretariat 2014) and 2014-2016 (SAICM Secretariat 2019b), were subsequently prepared. The Summary Report on progress in implementing the Strategic Approach for the period 2011-2013 was submitted to the fourth session of the International Conference on

**Figure 3.28** **Selected SAICM indicators, comparing results for 2009-2010 and 2011-2013 (adapted from SAICM Secretariat 2014, p. 13)**


The figure shows the average number of activities undertaken for each indicator as a percentage of all possible options for activities listed for the given indicator in the questionnaire. The indicators are listed in order of the greatest positive change between the first and the second reporting process.

**Figure 3.29** Progress against objectives since the first reporting period, by region for the reporting period 2011–2013 (per cent) (adapted from SAICM Secretariat 2015a, p. 4)




Note: World = IOMC and global organizations; Average = average for all regions and world categories of respondents
Objective A: Risk reduction
Objective B: Knowledge and information
Objective C: Governance
Objective D: Capacity building and technical cooperation
Objective E: Illegal international traffic

International Chemicals Management (ICCM4) (SAICM Secretariat 2015a).

In the second progress report there was a comparison, for selected SAICM indicators, of the results for 2009-2010 with those for 2011-2013. Figure 3.28 shows the average number of activities undertaken for each indicator as a percentage of all possible options for activities listed for the given indicator in the questionnaire (SAICM Secretariat 2014). The greatest increase observed in the number of activities selected was in indicator 3 (hazardous waste management arrangements).

The Summary Progress Report indicates progress by regions since the first report. As shown in Figure 3.29 progress across the regions differs significantly (SAICM Secretariat 2015a). A significant improvement in the range of activities was reported by respondents in the Western European and Other States between the first and second reporting periods. The CEE and LAC regions reported generally higher levels of activity during the second reporting period compared to the first, while the African and the Asia-Pacific regions reported fewer activities. The SAICM progress reports show that efforts in most countries focus on obligations stemming from legally binding instruments, particularly the Montreal Protocol and the Basel and Stockholm Conventions. Countries also reported a high level of activity on mechanisms to address pesticides and mercury, monitoring activities and national chemicals safety committees. The least commonly selected activities related to accessing finance (SAICM Secretariat 2012; SAICM Secretariat 2014).

Information for a third report on progress in the 2014-2016 period has been collected from stakeholders by the SAICM Secretariat. However, the report notes that the very low response rate does not allow comparison with previous reports, and it is therefore not feasible to measure progress using the information received from stakeholders (SAICM Secretariat 2019b).

## Results from the independent evaluation of SAICM

In 2016 SAICM started an independent evaluation of progress at the national and global levels, with the objective of collecting data to inform

**Box 3.5 SAICM independent evaluation: on-line survey of stakeholders**

The draft Independent evaluation of the Strategic Approach from 2006-2015 was presented to the second meeting of the intersessional process considering the Strategic Approach and the sound management of chemicals and waste beyond 2020 (SAICM Secretariat 2018b). An online survey was designed to capture SAICM stakeholder perceptions of the performance of SAICM. For a variety of SAICM parameters or activities, stakeholders were asked whether they considered work in this field to be very successful; having some success; having little success; unsuccessful; or whether they did not know the extent of success. Between November 2016 and January 2017, 212 respondents completed (or partially completed) the survey, of which 64 per cent were government representatives from across the five regions. The information in Tables 3.2 and 3.3 reflects the stakeholders' perceptions of levels of success.

decisions for the Strategic Approach and the sound management of chemicals and waste beyond 2020 (Box 3.5).

Stakeholder perceptions on achieving the OPS objectives, as obtained through the independent evaluation, are shown in Table 3.10 (SAICM Secretariat 2018b). For all the objectives the majority of respondents indicated that there was "some success". An average of 14 per cent indicated they did not know what the degree of success was, with a high percentage of 31 per cent in the case of objective E on illegal international traffic. The independent evaluation found that perceptions of the level of success in implementing the OPS objectives varied across regions.

Overall, the independent evaluation found that SAICM is unique in its ambition as an inclusive multi-stakeholder, multi-sector voluntary policy framework. It also found that SAICM creates a collaborative space for raising awareness, increasing knowledge and reducing risks. However, it pointed out weaknesses such as insufficient sectoral engagement; the capacity constraints of national focal points; lack of tools to measure progress; limited financing of activities; and insufficient and uneven advances in substantive areas such as illegal international traffic (SAICM Secretariat 2018b).

For each objective, however, and also in the various regions in most cases, the percentage indicating "some success" was highest. Some significant differences concern CEE stakeholders, of which 43 per cent considered implementation of "Objective A. Risk reduction" to be very successful, 71 per cent considered implementation of "Objective B. Knowledge and information" to be very successful, and 43 per cent considered implementation of the capacity building objective to be successful. Among civil society stakeholders, 35 per cent considered implementation of "Objective E. illegal international traffic" to be unsuccessful.

**Table 3.10 Stakeholder perceptions of the degree of success in achieving OPS objectives from 2006-2015, asked between 14 November 2016 to 4 January 2017 (SAICM Secretariat 2018b, p. 24)**

| OPS objective | Very successful (%) | Some success (%) | Little success (%) | Unsuccessful (%) | Don't know (%) |
|---|---|---|---|---|---|
| A. Risk reduction | 15 | 56 | 16 | 3 | 11 |
| B. Knowledge- and information-sharing | 22 | 54 | 14 | 2 | 7 |
| C. Governance | 16 | 47 | 20 | 5 | 12 |
| D. Capacity building and technical cooperation | 20 | 40 | 25 | 4 | 11 |
| E. Illegal international traffic | 7 | 27 | 18 | 18 | 31 |

**Table 3.11** **Stakeholder perceptions of the degree of success in incorporating the SAICM emerging policy issues (EPIs) and other issues of concern in activities from 2006-2015, asked between 14 November 2016 to 4 January 2017 (SAICM Secretariat 2018b, p. 32)**

| EPI/issue of concern | Start at ICCM number | (Co-)lead | Very successful (%) | Some success (%) | Little success (%) | Unsuccessful (%) | Don't know (%) |
|---|---|---|---|---|---|---|---|
| Lead in paint | 2 | UNEP/WHO | 27 | 29 | 5 | 6 | 34 |
| Chemicals in products | 2 | UNEP | 14 | 38 | 13 | 7 | 28 |
| HSLEEP | 2 | UNIDO | 12 | 20 | 15 | 11 | 41 |
| Nanotechnology/ nanomaterials | 2 | UNITAR/OECD | 18 | 19 | 14 | 10 | 38 |
| PFCs | 2 | OECD/UNEP | 11 | 27 | 10 | 8 | 44 |
| EDCs | 3 | OECD/UNEP/WHO | 24 | 22 | 12 | 9 | 32 |
| EPPP | 4 | UNEP/WHO | 8 | 22 | 13 | 10 | 46 |
| HHP | 4 | FAO/UNEP/ WHO | 22 | 26 | 10 | 6 | 36 |

HSLEEP: hazardous substances within the life cycle of electrical and electronic products; PFCs: perfluorinated chemicals and the transition to safer alternatives; EDCs: endocrine-disrupting chemicals; EPPP: environmentally persistent pharmaceutical pollutants; HHP: highly hazardous pesticides

## Results from the independent evaluation of the EPIs and other issues of concern

Table 3.11 shows the degree of success respondents considered they had had in incorporating emerging policy issues (EPIs) into their activities, as reflected in the independent evaluations (SAICM Secretariat 2018b). Details on progress with each EPI are given in Part II, Ch. 4. Perceptions of the level of success can differ significantly over regions and stakeholder groups, possibly reflecting the level of activity in the region or the level of engagement of the stakeholder groups involved. Examples are: for lead in paint, 50 per cent "very successful" in civil society and 40 per cent in the EU/JUSSCANNZ (Japan, the United States, Switzerland, Canada, Australia, Norway, New Zealand and other non-EU countries), while this was 0 per cent in the Asia-Pacific region; nanotechnology/ nanomaterials: 27 per cent "very successful" in EU/JUSSCANNZ and 43 per cent "little success" in the CEE region; hazardous substances within the life cycle of electrical and electronic products (HSLEEP): 50 per cent "some success" in the Asia-Pacific region and 50 per cent "little success" or "unsuccessful" in the African region; and endocrine-disrupting chemicals (EDCs): 42 per cent "very successful" in industry and 0 per cent in the LAC region.

The evaluation noted that the identification of (and actions taken on) the eight EPIs and other issues of concern were a major strength and uniqueness of SAICM, and that the IOMC participating organizations have been actively involved in leading activities on the EPIs (SAICM Secretariat 2018b). Nevertheless, it found that progress in implementing the EPIs has been slow, modest and uneven.

# 4/ Emerging policy issues and other issues of concern

## Chapter Highlights

A process has been established under SAICM to identify emerging policy issues (EPIs) and other issues of concern; to date, eight issues have been identified by the international community.

The nomination of the EPIs and other issues of concern has successfully raised awareness, focused the attention of stakeholders and catalysed initiatives; however, challenges remain.

In addressing lead in paint, hazardous substances within the life cycle of electrical and electronic products (HSLEEP) and highly hazardous pesticides (HHPs), further collaborative action can be taken, including at the international level, to further minimize risks.

In addressing chemicals in products, polyfluorinated chemicals (PFCs) and environmentally persistent pharmaceutical pollutants (EPPPs), further awareness-raising and transparency could advance the international agenda and circularity.

Further research and knowledge generation is needed in all regions on nanotechnology and endocrine-disrupting chemicals (EDCs), including through a strengthened science-policy interface

To date, the International Conference on Chemicals Management (ICCM) has identified eight emerging policy issues (EPIs) and other issues of concern, understood to be issues involving any phase in the life cycle of chemicals and which have not yet been generally recognized; are insufficiently addressed or arise from the current level of scientific information; and which may have significant adverse effects on human health and/or the environment. In light of the UNEA mandate to address the EPIs, the GCO-II provides evidence concerning a number of remaining challenges and presents a range of measures to further address existing EPIs and other issues of concern. While no assumptions are made about these potential measures being carried forward in the beyond 2020 process, they are considered to be of relevance for further consideration by stakeholders.

## 4.1 Emerging policy issues and other issues of concern: a core element of SAICM

In 2016 the second United Nations Environment Assembly (UNEA-2) requested the Executive Director of the UN Environment Programme to "ensure that the update of the Global Chemicals Outlook (GCO-II) addresses the issues which have been identified as emerging policy issues by the ICCM, as well as other issues where emerging evidence indicates a risk to human health and the environment."

One of the functions of the ICCM, set out in the Overarching Policy Strategy (OPS) of the SAICM, is "to focus attention and call for appropriate action on emerging policy issues as they arise and to forge consensus on priorities for cooperative action". In accordance with that function, the ICCM has discussed "emerging policy issues" (EPIs) from its second session (ICCM2, held in 2009) onwards.

The Annex to Resolution II/4 adopted at ICCM2 sets out an open and transparent five-step procedure for the consideration of emerging policy issues:

- *Call for nominations*: Any SAICM stakeholder is free to nominate EPIs. While nominations are possible at any given time, stakeholders are formally invited at specific periodic intervals, e.g. in the lead-up to each ICCM.

- *Submission of initial information*: In nominating an EPI, proponents are required to provide information on why the issue is considered an EPI, in particular how it is consistent with the definition of an EPI (i.e. an issue involving any phase in the life cycle of chemicals and which has not yet been generally recognized, is insufficiently addressed or arises from the current level of scientific information, and which may have significant adverse effects on human health and/or the environment) and how the issue meets the selection criteria (see below), and a description of the proposed cooperative action. Moreover, proponents are encouraged to include a description of proposed actions to be considered in moving forward on the EPI.

- *Initial review and publication of submissions*: The secretariat sets out the results of a screening of the nominated EPI against the agreed criteria and compiles a list of nominations, thereby clustering similar nominations. The list of nominations is made publicly available for comments and thereafter consolidated.

- *Prioritization through consultation and advice from stakeholders and experts*: After publication of the nomination list, the regions may prioritize submissions by engaging formally the full range of their stakeholders.

- *Inclusion of EPIs on the provisional agenda of the Conference*: The Open-ended Working Group will consider the regional inputs and other information to assess the proposals, taking into account the criteria below, and proposes a limited number of priority EPIs to the Conference for its consideration.

To provide a basis for further considering the priority of each nominated EPI, the following criteria were developed:

1. Magnitude of the problem and its impact on human health or the environment, taking into account vulnerable subpopulations and any toxicological and exposure data gaps.

2. Extent to which the issue is being addressed by other bodies, particularly at the international level, and how it is related to, complements, or does not duplicate such work.

3. Existing knowledge and perceived gaps in understanding about the issue.

4. Extent to which the issue is of a cross-cutting nature.

5. Information on the anticipated deliverables from action on the issue.

So far, resolutions have been adopted on the following issues at ICCM2, ICCM3 and/or ICCM4:

- Lead in paint (ICCM2, 2009);

- Chemicals in products (ICCM2, 2009);

- Hazardous substances within the life cycle of electrical and electronic products (ICCM2, 2009)

- Nanotechnology and manufactured nanomaterials (ICCM2, 2009);

- Per- and polyfluoroalkyl substances (PFASs) and the transition to safer alternatives (ICCM2, 2009);

- Endocrine-disrupting chemicals (ICCM3, 2012);

- Environmentally persistent pharmaceutical pollutants (ICCM4, 2015) ; and

- Highly hazardous pesticides (ICCM4, 2015).

## 4.2 Working towards further risk reduction

### 4.2.1 Lead in paint: enhanced action required to meet the 2020 phase-out targets

#### Introduction

Lead is a metal and a potent neurotoxin, whose widespread use has caused extensive environmental contamination and health problems in many parts of the world (WHO 2010a; WHO 2010b). Even though lead in paint[1] is one of the main sources of exposure for children, it continues to be used in over 70, and potentially more than 100, countries to enhance colour, reduce corrosion or reduce drying time (WHO 2010a; UNEP and IPEN 2013; IPEN 2017; UNEP 2017a; WHO 2017a). An estimated 11 per cent of global decorative paint production takes place in countries where its use is not regulated (International Paint and Printing Ink Council [IPPIC] 2015). In addition, some of the world's largest economies which are restricting domestic use of lead paint continue to export lead pigments and lead paint (Kessler 2014; Gottesfeld 2015; IPEN 2016).

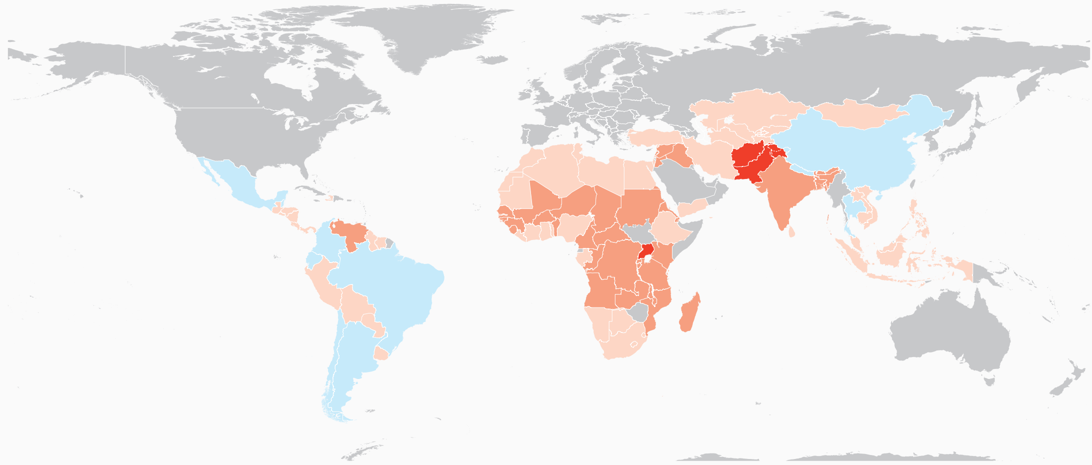
In 2009 the International Conference on Chemicals Management (ICCM) identified lead in paint as an emerging policy issue. The Global Alliance to Eliminate Lead Paint (GAELP), also known as Lead Paint Alliance, was established and included in its business plan the target that by 2020 all countries should have legally binding controls on lead paint (UNEP and WHO 2012). The global target to eliminate lead paint by 2020 was reaffirmed at the Fourth Session of the ICCM in 2015. While considerable action has been taken, the elimination of lead in paint, and the introduction of safe alternatives to lead pigments in paints, remains a challenge in many countries.

#### State of the issue

No safe level of exposure to lead has been identified. While it is well known that exposure to levels of lead that were previously considered to be acceptable can cause serious and irreversible health effects, including reduced intelligence quotient scores, there is now a scientific consensus that even low levels of exposure to lead are potentially harmful and may cause intellectual deficits (Fewtrell, Kaufmann and Prüss-Üstün 2003; Nevin 2007; Verstraeten, Aimo and Oteiza 2008; WHO and UNEP 2009; WHO

1 The preferred terminology by the Global Alliance to Eliminate Lead Paint (GAELP) is "lead paint", which it defines as "paint to which one or more lead compounds have been added and includes varnishes, lacquers, stains, enamels, glazes, primers and coatings used for any purposes" (WHO and UNEP 2012).

**Figure 4.1** Economic costs of childhood lead exposure in low- and middle-income countries (percentage of gross domestic product) (adapted from Attina and Trasande 2013)




2010a; United States National Toxicology Program [US NTP] 2012; Health Canada 2013a; Schnur and John 2014; Evens *et al.* 2015; Gottesfeld 2015; Aizer *et al.* 2018). Health impacts of lead have resulted in significant economic and social costs (WHO and UNEP 2009). Childhood lead toxicity, with lead paint a major source of exposure, has been estimated to cost low- and middle-income countries US dollars 977 billion per year (Attina and Trasande 2013) (Figure 4.1).

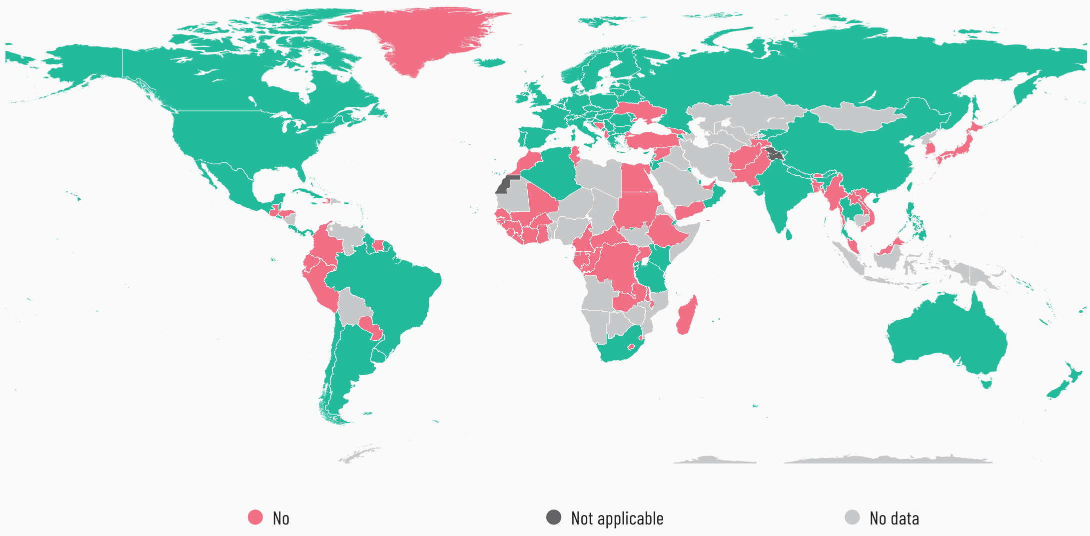
Lead can be harmful to people of all ages, with children, infants and foetuses being particularly at risk. The main sources of exposure for infants and children are food and drinking water, household dust, soil, and mouthing of products containing lead. The most common source will vary based on geography and lifestyle (United States Centers for Disease Control [US CDC] 2010); Health Canada 2013b; UNEP and IPEN 2013; Etchevers *et al.* 2015; US CDC 2016). Recent research indicates that even in countries where lead paint is regulated, high lead concentrations can be found in paint on playground surfaces (Turner *et al.* 2016). Workers are also at high risk, as large quantities of lead can be released during manufacturing, application and removal of lead paint (WHO and UNEP 2009). A significant proportion of housing in developed countries still contains legacy lead paint (US NTP 2012; Dewalt *et al.* 2015).

## Policy developments and considerations

The momentum to reduce the use of lead in paints has resulted in a number of countries adopting legislation in recent years (Figure 4.2). As of September 2017, 67 countries had confirmed that they had legally binding controls on lead in paint, 70 countries had stated that they did not have such legislation, and information was unavailable for 56 countries (UNEP 2017a). Even in countries with adequate regulations, weak enforcement has resulted in continued manufacture and sale (Kessler 2014; Gottesfeld 2015; IPEN 2016). Despite significant progress and successful engagement of stakeholders, including through the Lead Paint Alliance, challenges remain, particularly in developing countries. These challenges include the lack of country-specific data, laboratory capacity, public awareness of lead toxicity, and knowledge of alternatives (Kessler 2014; IPEN 2017; UNEP 2017a).

Continued production may be motivated by cost considerations and export opportunities (Kessler 2014). Lead pigments are readily available and relatively easy to manufacture. Moreover, SMEs may lack the knowledge to reformulate (UNEP and IPEN 2013; Kessler 2014; Gottesfeld 2015). However, there is evidence that it is technically and economically feasible to replace lead

**Figure 4.2** Status of lead paint regulation worldwide, as reported in 2017 (adapted from WHO 2018a)




additives (IPPIC 2015). Several manufacturers have thus successfully eliminated lead from all paints (Curl 2013; UNEP and IPEN 2013; Kessler 2014; UNEP 2017a). Manufacturers in low-income countries which have successfully switched have described increases in materials costs as insignificant (UNEP and IPEN 2013). Innovative initiatives are also under way: in 2016 a multi-stakeholder group in the Philippines established the world's first programme to certify paints containing less than the recommended 90 parts per million lead (IPEN 2017).

### Potential measures to further address lead in paint

Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further address lead in paint:

- Urgently ensure that all countries have legally binding controls in place as an effective and simple means to phase out the manufacture, sale and use of lead in paint.
- Strengthen enforcement at the national level, including through increasing laboratory capacity.
- Address non-consumer use of lead paint and legacies of lead paint in buildings, complementing efforts targeting consumer uses.
- Restrict the export of lead pigments and lead paints to accelerate the transition in countries still using lead.
- Scale up awareness-raising activities and the use of innovative initiatives, such as independent third-party verification schemes.
- Use economic tools and incentives that target both supply and demand, including assistance to small and medium-sized paint manufacturers and the use of levies to increase the cost of lead paint or subsidies for lead-free paint.

## 4.2.2 Hazardous substances within the life cycle of electrical and electronic products

### Introduction

The production and use of electrical and electronic products containing hazardous substances, including substances whose risks have not been fully characterized, is rapidly increasing (Tsydenova and Bengtsson 2011; UNIDO 2015; Scruggs, Nimpuno and Moore 2016; Fowler 2017). End-of-life electrical and electronic products ("e-waste") constitute the fastest growing waste stream in the world, and their recycling rates remain low in many countries (Baldé *et al.* 2017; Cecere and Martinelli 2017).

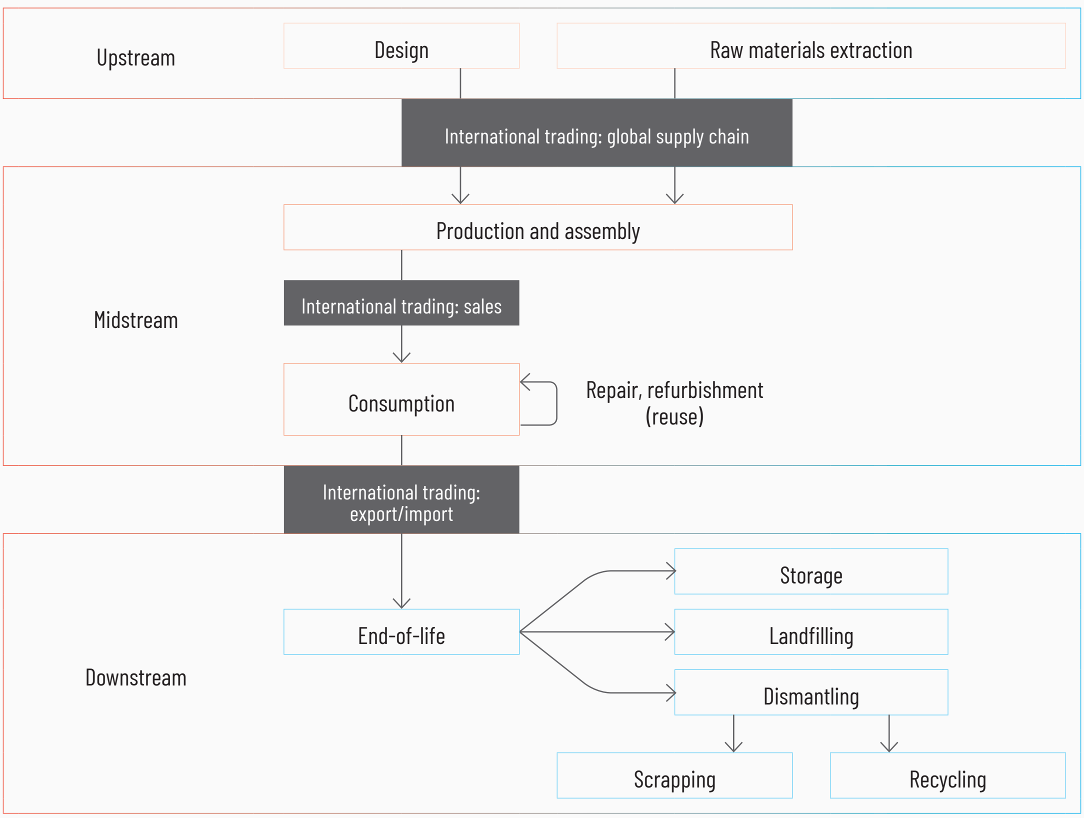
All the countries in the world combined generated approximately 44.7 million tonnes of e-waste in 2016, the equivalent of 6.1 kilograms per inhabitant. Asia generated the largest amount of e-waste, followed by Europe and the Americas. Out of the amount generated, only 20 per cent was recycled through formal channels (Baldé *et al.* 2017). Informal and rudimentary recycling methods, as well as uncontrolled disposal, are releasing chemical pollution, thus creating concerns for human health and the environment (Fujimori *et al.* 2012; Premalatha *et al.* 2014; Awasthi *et al.* 2016; Heacock *et al.* 2016; Baldé *et al.* 2017).

In light of these considerations, "hazardous substances within the life cycle of electrical and electronic products" was adopted as an Emerging Policy Issue (EPI) at the second ICCM in 2009. Conscious that actions are needed up-, mid- and downstream, a life cycle approach (Figure 4.3) was endorsed. Despite valuable efforts made at all levels, significant challenges remain in regard to identifying, disseminating and implementing best practices at all stages of the life cycle, including design, recycling and disposal (Secretariat of the Basel Convention and UNIDO 2011; UNIDO 2015).

## State of the issue

In the manufacturing of electrical and electronic products workers may come into direct contact with hazardous chemicals, which can result in significant adverse effects including high cancer rates (Kim *et al.* 2012; Chou *et al.* 2016). Some studies indicate that in some countries women make up the majority of assembly line workers in the electronics industry; therefore, women may be disproportionately affected (Koh, Chan and Yap 2004), which has been reported to have implications for reproductive outcomes (Kim *et al.* 2012; Rim 2017). Consumers also experience

**Figure 4.3** **The life cycle of electronic and electrical products (adapted from Secretariat of the Basel Convention and UNIDO 2011)**



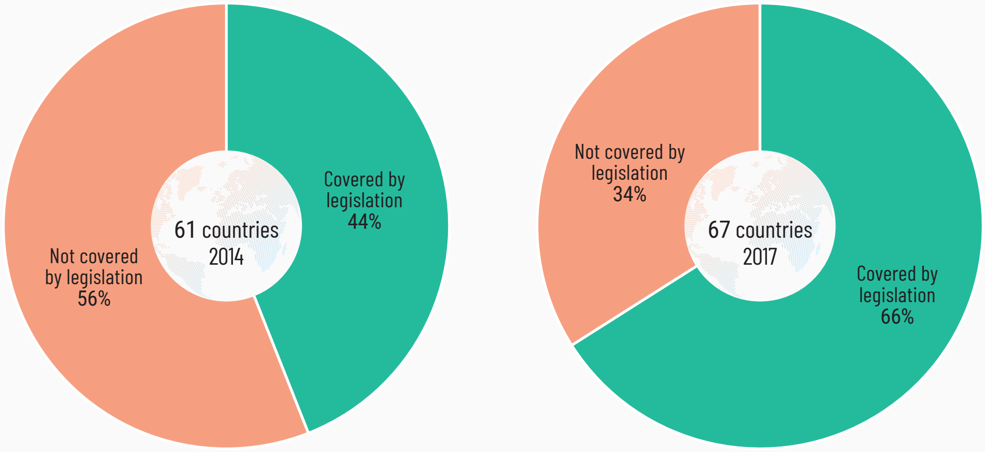
exposures in the use phase, typically in indoor environments (Miller *et al.* 2016; Zheng *et al.* 2017; Kuang, Abdallah and Harrad 2018). This includes children, who may, for example, be exposed to flame retardants in dusts released from electronic products (Danish Environmental Protection Agency 2017). Downstream, hazardous substances can be released from e-waste during disposal and recycling, affecting ecosystems by contaminating the air, water and soil and entering food chains (Wang *et al.* 2005; Duan *et al.* 2011; Fu *et al.* 2013; Yu *et al.* 2016; Anh *et al.* 2017; Klees, Hombrecher and Gladtke 2017; Chakraborty *et al.* 2018).

The adverse effects on human health, particularly among recycling workers in developing countries relying on informal and rudimentary methods, are significant and include increased risks of cancer and negative effects on the reproductive, cardiovascular and immune systems (Tsydenova and Bengtsson 2011; Grant *et al.* 2013; Song and Li 2014; Song and Li 2015; Zheng *et al.* 2016). Women and children, as well as those living in the vicinity of recycling sites, remain among the most vulnerable groups (Eguchi *et al.* 2012; Song and Li 2014; Song and Li 2015; Xu *et al.* 2017; Schecter *et al.* 2018). Lacking or insufficient classification of wastes poses challenges in understanding potential risks and determining appropriate disposal options (Mmereki *et al.* 2016).

## Policy developments and considerations

A growing number of countries are adopting e-waste legislation (Baldé *et al.* 2017) (Figure 4.4). This includes, for example, India's E-Waste Management Rules, adopted in 2016 (Ministry of Environment, Forest and Climate Change of India 2016) and the EU Waste Electrical and Electronic Equipment Directive, revised in 2012 (European Commission [EC] 2012a). Legislation targeting the up- and midstream life cycle includes the EU's Restriction of Hazardous Substances Directive (EC 2017a). The global nature of supply chains has prompted a number of countries to develop similar legislation (Selin and Van-Deveer 2006; van Rossem, Tojo and Lindhqvist 2006), including China and the United States (Congress of the United States 2009). International regulatory frameworks focusing on the downstream phase include the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, and the Bamako Convention on the Ban on the Import into Africa

**Figure 4.4** **Percentage of the world population and number of countries covered by e-waste legislation in 2014 and 2017 (adapted from Baldé *et al.* 2017, p. 6)**




and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa. However, challenges remain: 34 per cent of the world population is currently not covered by national e-waste management laws, and illegal traffic remains a major challenge even in countries with regulations (Geeraerts *et al.* 2015; Baldé *et al.* 2017).

Several major companies have voluntarily eliminated substances of concern from their product lines (Cobbing and Dowdall 2014). Criteria-based approaches have also been taken by several large electronics companies which could make regulators' tasks in testing and verifying products easier (Nimpuno, McPherson and Sadique 2009). In addition, civil society organizations undertake monitoring activities and inform consumers by ranking consumer electronics companies according to their commitment to, and progress in, eliminating hazardous chemicals from manufacturing and from the product itself (Cobbing and Dowdall 2014; Cook and Jardim 2017). In parallel, strategies are being explored to advance "sustainable electronics" designed for a closed-loop system (O'Connor *et al.* 2016).

### Potential measures to further address HSLEEP

Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further address HSLEEP:

- Accelerate regulatory action in all countries to protect workers, consumers and recyclers, including mid- and upstream legislation, criteria-based approaches, extended producer responsibility, and "green taxes".
- Develop a global framework of accountability and close data gaps on the presence, flow and transboundary movement of hazardous substances throughout the life cycle, thereby exploring synergies with the Strategic Approach to International Chemicals Management (SAICM) Chemicals in Products (CiP) Programme.
- Take global action to encourage the design of a new generation of green electronics with minimized use of hazardous substances, longer life spans and increased recyclability.
- Improve understanding of the role and impact of the informal sector and explore concrete steps to reduce the exposure of recycling workers, including through promotion of best practices;
- Scale up voluntary initiatives and sustainable business models.
- Fuel shifts in consumer behaviour through increased awareness.

### 4.2.3 Highly hazardous pesticides

#### Introduction

The FAO and WHO International Code of Conduct on Pesticide Management defines highly hazardous pesticides (HHPs) as: "Pesticides that are acknowledged to present particularly high levels of acute or chronic hazards to health or environment according to internationally accepted classification systems such as the WHO or the GHS or their listing in relevant binding international agreements or conventions. In addition, pesticides that appear to cause severe or irreversible harm to health or the environment under conditions of use in a country may be considered to be and treated as highly hazardous." The FAO/WHO Guidelines on Highly Hazardous Pesticides (2016) list a set of eight criteria: HHPs are defined as meeting one or more of these criteria. The guidelines apply to all pesticides, including agricultural, public health, household, amenity and industrial pesticides. The FAO/WHO Joint Meeting on Pesticide Specifications (JMPS) also developed standard procedures for assessment of pesticide data (WHO and FAO 2016).

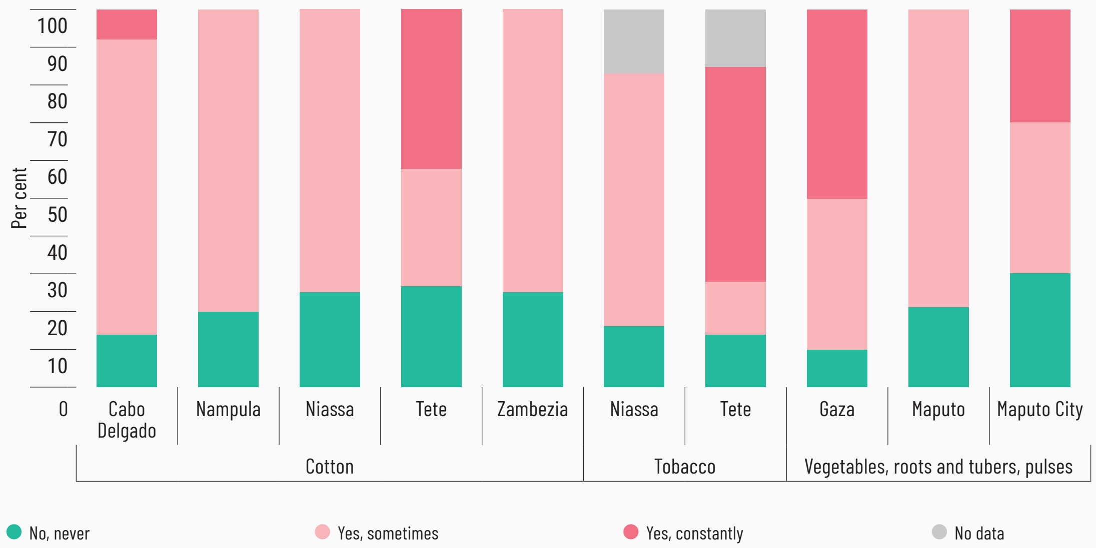
Plant protection products and biocides, when managed safely, can make an important contribution to achieving Sustainable Development Goal (SDG) 2 (zero hunger), SDG 3 (good health and well-being) and SDG 6 (clean water and sanitation), among others. However, HHPs in particular may have adverse effects on human health, the environment and the sustainability of agricultural production, especially in low- and middle-income countries (LMICs). In 2015, therefore, the ICCM adopted a resolution that recognized HHPs as an issue of concern and called for concerted action to address HHPs, in particular through implementation of the strategy that was presented to the Conference (SAICM Secretariat 2015a; SAICM Secretariat 2015b).

#### State of the issue

Exposure of humans and other non-target organisms has been shown to be high if plant protection products are not used according to best practices (Fan *et al.* 2015), highlighting the importance of education and awareness. This is of special importance in LMICs, where training and adequate knowledge on risks, handling and safety measures, access to and appropriate conditions for use of personal protective equipment (PPE), and potential alternatives might be lacking (Dalvie, Rother and London 2014; Andrade-Rivas and Rother 2015; Weiss *et al.* 2016, Elibariki and Maguta 2017; Rother 2018). A related challenge is the very low rate at which pesticide containers are disposed in an environmentally sound manner. Research in developing countries shows that they are frequently discarded, burned, or reused, for example in toys or to store food or water (Akhter *et al.* 2016; Rengam *et al.* 2018). Another concern is lack of enforcement, whereby uncontrolled access to HHPs has led to unintended uses, and plant protection products that are banned in high-income countries and do not meet international quality standards continue to be marketed in some LMICs (Popp, Pető and Nagy 2013; Rother 2016). Adherence to best practices in the use of biocides is of equal concern.

Certain HHPs can exhibit high acute toxicities on non-target organisms, including plants, animals and humans (Mañosa, Mateo and Guitart 2001; Brühl *et al.* 2013; Kohler and Triebskorn 2013; Fleischli *et al.* 2004). Studies show adverse effects on various animal species (Galloway and Depledge 2001; Mañosa, Mateo and Guitart 2001; Galloway and Handy 2003; Hamlin and Guillette 2010; Hayes *et al.* 2010; Kohler and Triebskorn 2013). Scientific studies have also associated exposure to pesticides with chronic effects in humans, including increased risks for some cancers, birth defects, adverse effects on organs and reproduction, and pulmonary disease (Merhi *et al.* 2007; Vinson *et al.* 2011; Sarwar 2016; Kim, Kabir and Jahan 2017; Mostafalou and Abdollahi 2017). These concerns also apply to biocides, which often contain the same active ingredients as plant protection products and are applied in close proximity to humans (e.g. mosquito repellents) or in the environment (e.g. anti-fouling). Increasing insecticide resistance is another major concern, particularly in the fight against malaria (WHO 2018b).

**Figure 4.5** **Discomfort or illness experienced during or after pesticide application in Mozambique (per cent) (adapted from Mancini *et al.* 2016, p. 16)**




In a field survey undertaken in Mozambique, the majority of farmers reported symptoms of pesticide exposure or poisoning (Figure 4.5). While there are significant data gaps, countries are reporting a significant number of deaths every year from unintentional pesticide poisonings (WHO 2018c) (see also Part I, Ch. 7). A survey undertaken by the Pesticide Action Network (PAN) (Rengam *et al.* 2018) in seven Asian countries found that the majority of surveyed farmers had experience acute poisoning symptoms over a one-year period. Moreover, the WHO estimated that in 2012 around 156,000 suicides using pesticides could have been prevented by sound pesticide management (WHO 2016) (Box 4.1).

## Policy developments and considerations

The IOMC, under the leadership of the FAO, supports countries and captures progress in addressing HHPs, including at the regional and national levels. A strong political will to mitigate

**Box 4.1 Preventing suicides attributable to pesticides through regulatory measures in Sri Lanka (Manuweera *et al.* 2008; Knipe et al. 2017)**

As in many other low- and middle-income countries, a large number of suicides in Sri Lanka can be attributed to access to toxic pesticides. To address this challenge Sri Lanka has taken a range of regulatory measures over the past decades, including import bans on WHO Class I pesticides and endosulfan as well as a more recent phased import ban (2008-2011) on three additional pesticides. Studies suggest that these restrictions can be associated with a significant decrease in pesticide suicide mortality and overall suicide mortality in Sri Lanka. While restricting access to HHPs cannot solve the global challenge of suicides, data show that it decreases the number of suicides at least in the short to medium term. The bans were found not to have resulted in productivity loss or changes in the costs of production.

the impact of HHPs has been built in Africa and Asia and the Pacific. A significant step forward with respect to regional strategies in South Africa, East Africa and the Pacific has been taken in the context of three large regional consultations held in 2018.

In the context of a project implemented by the FAO, Mozambique cancelled the registrations of 61 pesticide products containing 31 different active ingredients and announced risk reduction measures for another 52 pesticide products (FAO 2016). Botswana, Malawi, Tanzania and Zimbabwe have developed short lists of HHPs and started to reduce their risks. Further examples include China, where 23 highly hazardous pesticides have been banned from use, and Ecuador, where all pesticides classified as extremely or highly hazardous by the WHO were banned in 2010 (FAO and WHO 2010). According to a list developed by the PAN, a total of 370 pesticide active ingredients or groups of actives considered to be still in use have been banned in at least one country (PAN 2016). Some pesticides have been internationally banned under the Stockholm Convention on POPs due to their toxicity, persistence, bioaccumulation, and potential for long-range transport. However, the enforcement of bans remains a challenge in LMICs (Khan, Mahmood and Damalas 2015; Yadav *et al.* 2015; Weiss *et al.* 2016; Elibariki and Maguta 2017; Thompson *et al.* 2017).

Several international instruments and initiatives exist to support stakeholders in managing pesticides and addressing risk associated with pesticides. These include the Joint FAO/WHO Meeting on Pesticide Management (JMPM) recommendations on the conditions of use of HHPs (FAO and WHO 2007), the International Code of Conduct on Pesticide Management (FAO and WHO 2014a), the FAO/WHO Guidelines on Highly Hazardous Pesticides (FAO and WHO 2016) and the FAO Pesticide Registration Toolkit (FAO 2018a), and the OECD Best Practice Guidance to Identify Illegal Trade of Pesticides (OECD 2018a). Some have raised concerns about cases of non-compliance with some of these tools, for example regarding the distribution of HHPs (Public Eye 2017). Although efforts have been made to broaden the scope of existing instruments and initiatives beyond plant protection products (e.g. the updated Code of Conduct of 2014 incorporates public health pesticides and vector control [FAO and WHO 2014b]), biocides have so far received limited international attention.

Industry is addressing the issue among others through risk mitigation and capacity building initiatives such as training of farmers (e.g. CropLife International 2018); measures to address the counterfeit pesticide market; and voluntary portfolio review to withdraw products meeting the Code's HHP hazard criteria from the market (FAO/WHO 10th JMPM 2017). Civil society stakeholders contribute among others by monitoring of the conditions of use and adverse impacts, awareness-raising; the promotion of additional health and environmental criteria for the identification of HHPs (such as pollinator toxicity); and a proposed list of pesticides considered to be highly hazardous (Rengam *et al.* 2018).

Given the recommendation to reduce reliance on pesticides as the first step in risk reduction (FAO and WHO 2016), research and the implementation of alternative practices have gained momentum. Integrated pest management combines various management strategies and practices in order to grow healthy crops and minimize the use of pesticides (FAO 2018b). Similarly, integrated vector management is a process for decision-making when carrying out disease vector control interventions for control of vector-borne diseases (FAO and WHO 2014b). Agroecological approaches aim at pest prevention and promote agricultural practices adapted to local environments in order to build long-term fertility and soil health (Huang *et al.* 2014; Reddy 2016; United Nations Human Rights Council 2017). A recent meta-study in France found that total pesticide use could be reduced by 42 per cent without loss of productivity and profitability (Lechenet *et al.* 2017). There is also ongoing scientific advancement in the development of bio-pesticides (Senthil-Nathan 2015). Moreover, there are ongoing discussions, including in the context of the JMPM meetings about the use of the "Hierarchy of Control"approach for pesticide risk reduction; however, no consensus and common understanding has emerged to date (FAO and WHO 2017). According to the Guidelines on Highly Hazardous Pesticides (FAO and WHO 2016), the approach to pesticide risk reduction comprises three main steps, namely to 1) reduce reliance on pesticides; 2) select pesticides with the lowest risk; and 3) ensure proper use of the selected products. Possible measures to reduce the use of biocides have also been proposed (German Environment Agency [UBA] 2014).

#### Potential measures to further address HHPs

Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further address HHPs:

- Strengthen international and national action to speed up ending use of highly hazardous pesticides (HHPs) based on a risk and needs assessment and reduce their use in food production and supply chain, including via implementation of the strategy to address HHPs in the context of the Strategic Approach to International Chemicals Management (SAICM).

- Support the development and scaling-up of approaches that may help to reduce the use of highly hazardous pesticides, such as IPM and agroecological approaches, including development and use of non-chemical alternatives and other good agricultural practices, among others via awareness-raising and training of users.

- Strengthen legislative frameworks and enforcement for the regulation of pesticides in general, and HHPs in particular, throughout the life cycle and improve capacity for enforcement.

- At the local level, provide basic infrastructure and training, particularly in developing countries and economies in transition, to promote comprehension of pesticide labels, best practices in handling and application, and the use of and access to personal protective equipment (PPE).

- Increase efforts to synthesize available information and make it more easily available to the public and to decision makers, e.g. via the establishment of knowledge hubs featuring relevant information on HHPs.

- Advance discussions on issues related to biocides and measures to address and reduce the use of biocides, including though regulatory action, and strengthen awareness.

## 4.3 Working towards improved transparency and awareness raising

### 4.3.1 Chemicals in products

#### Introduction

Chemicals are important components in many of the products modern society uses and relies on (Goldenman *et al.* 2017). They may be released at any stage of the product life cycle, resulting in potential exposures of humans and the environment, including from both newly produced articles and articles already present in society (Fantke *et al.* 2016; Reihlen 2017) (see Figure 4.6). The Swedish Chemicals Agency (KEMI 2015) has stated that sharing, tracking and using reliable chemical information throughout the supply chain is a prerequisite for a non-toxic and resource-efficient product life cycle.

In light of these considerations, Chemicals in Products (CiP) was identified as an emerging policy issue at the second meeting of the ICCM (ICCM2) in 2009. Stakeholders of the Strategic Approach to International Chemicals Management (SAICM) also identified four priority sectors: textiles, toys, building products and electronics (SAICM Secretariat 2009a). In 2015, at ICCM4, stakeholders adopted the SAICM Chemicals in Products (CiP) Programme and agreed on three main objectives for CiP information exchange (UNEP 2015):

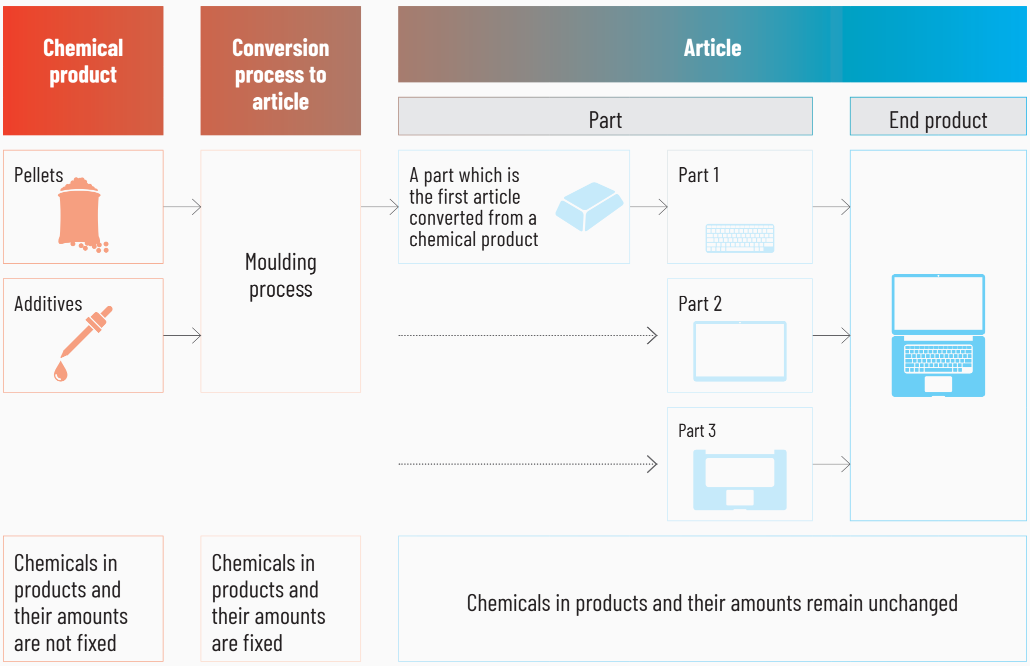
- within supply chains, to know and exchange information on CiP, associated hazards and sound management practices;
- to disclose information of relevance to stakeholders outside the supply chain to enable informed decision making and actions about CiP; and
- to ensure that, through due diligence, information is accurate, current and accessible.

To support these efforts, guidance on CiP for stakeholders was developed (UNEP 2015). ICCM4 encouraged participants to consider this guidance as appropriate (SAICM Secretariat 2015b).

## State of the issue

The exchange of important aspects of CiP information throughout the supply chain has been advanced by diverse stakeholder action. A number of countries and state jurisdictions have put in place CiP policies and legislation, including on the CiP programme priority sectors, but also going beyond. For example, regulations such as REACH Article 33 in the EU, and Proposition 65 in the State of California in the United States, require producers to pass certain CiP information on to consumers in the supply chain (EC 2006; Office of Environmental Health Hazard Assessment of California [OEHHA] 2018). The EU Waste Electrical and Electronic Equipment (WEEE) Directive and other similar directives, such as China's on WEEE, regulate communication between producers, consumers and end-of-life

**Figure 4.6** Conversion process from chemical products to articles in the supply chain (adapted from ©Joint Article Management Promotion-consortium 2018, p. 12)



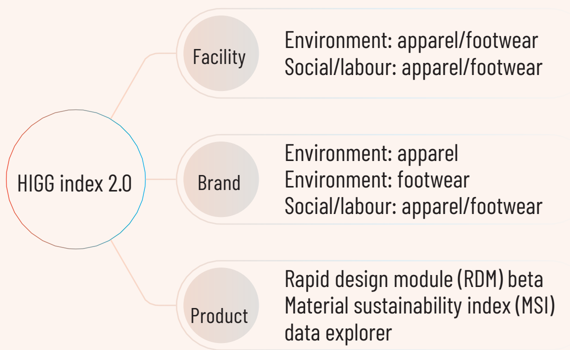
users (Mishima 2017). For cosmetics and personal care products in the EU, the United States and Japan, separate regulations require producers to communicate all ingredients to the consumer (Japan External Trade Organization [JETRO] 2011; Cosmetics Europe 2018; United States Food and Drug Administration [US FDA] 2017). Other examples of tools for communication between producers and customers include the declarations of performance according to the European Construction Products Regulation (EC 2011a) and use of the CE marking for the safety of toys (EC 2009a).

In the private sector examples of sector-specific systems include the International Material Data System (IMDS), an information system developed by the automotive industry, and BOMCHECK, the joint declaration platform for the electronics industry. In the United States the Toy Safety Certification Program was initiated in response to new Federal Toy Safety requirements (Kogg and Thidell 2010). To foster transparency, some companies are making their safety data sheets (SDS) publicly available (Scruggs *et al.* 2014). Moreover, some electronics multinationals have encouraged their suppliers to report pollutant release and transfer data across supply chains (DiGangi 2018). In the apparel industry, the Higg Index is being used by over 2,000 members of the Sustainable Apparel Coalition (Box 4.2).

Non-regulatory actions to advance the objectives of the CiP Programme include consumer awareness projects, certification programmes, and the publication of restricted substance lists (RSLs). In 2017 CVS Health published its full list of restricted chemicals by product category (CVS Health 2017). Consumer awareness projects provide information on chemicals of concern in certain products and help consumers make informed choices. An example is the "Mind the Store" initiative, which evaluates retailers' progress in tackling chemicals of concern, including their policies to collect chemical ingredient information from suppliers and make relevant information publicly available (Safer Chemicals, Healthy Families 2017). Certification programmes are voluntary initiatives in which companies can participate to communicate that their products meet certain requirements, while not revealing confidential business information. These programmes may include RSLs and requirements for chemical analysis.

**Box 4.2 The Higg Index: advancing sustainability in the apparel industry (Hughes, Kibbey and Rudgeway 2014)**

The Higg Index is a suite of self-assessment tools for measuring the environmental and social impact of apparel, footwear and home textile production. It encourages companies of all sizes in the fashion industry to adopt sustainable practices and to integrate sustainability information into their reporting cycle. The assessments cover brands, retailers, facilities and products, thus helping members to adopt a holistic, consistent approach to managing sustainability performance.



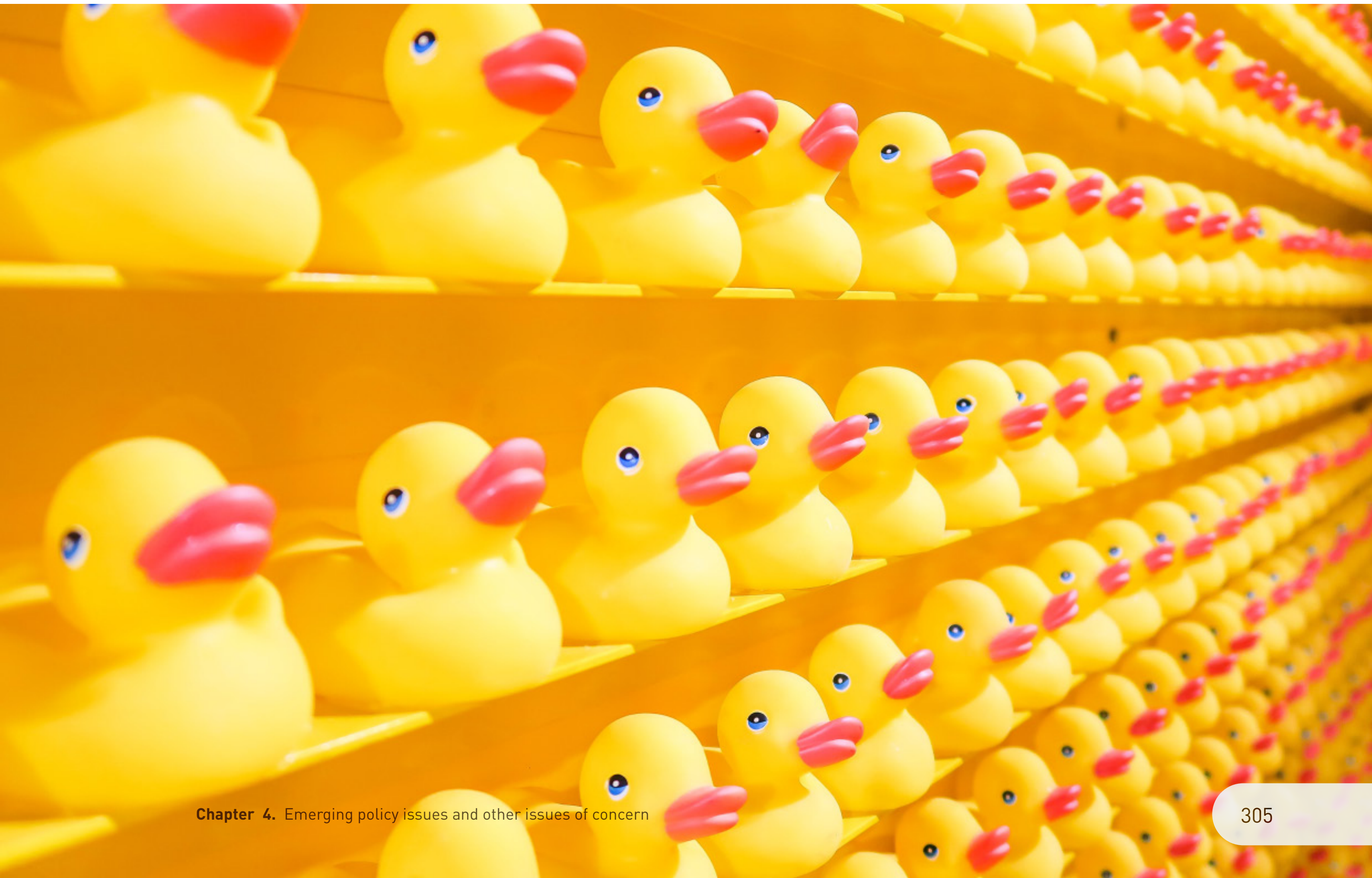

The index also allows downstream and upstream information exchange across the value chain, increasing transparency and encouraging stakeholders to improve performance. Currently, over 2,000 members of the Sustainable Apparel Coalition are using the Higg Index.

Information technology (IT) solutions have also improved the quality and reliability of data in supply chains. New opportunities are emerging, such as the use of block chain technology in tracing chemical information throughout the supply chain (Casey and Wong 2017). Models (e.g. the UN Environment/Society of Environmental Toxicology and Chemistry Lifecyle Initiative's USEtox model) support the characterization of human and ecotoxicological exposures to CiP. The CiP Programme has developed an indicative list of information exchange schemes and tools that already existed in different sectors.

Despite these advances, gaps remain. For example, while chemical information is often available in the upstream of the supply chain (UNEP 2011), downstream companies have reported difficulties in identifying chemicals in materials and products "because relevant information was not communicated to them in usable forms in their supply chains" or was "lost in the supply chain" or was "protected by trade secrets" (Scruggs *et al.* 2014). Furthermore, lack of data on the concentration of chemicals in products is considered a main limitation in assessing exposure to chemicals in products (Fantke *et al.* 2016). Another potential challenge is that consumers who lack knowledge on chemicals of concern may not be able to use the information that is made available in an informed manner.

## Policy developments and considerations

Recent years have seen a momentum in transparency requirements by governments across products and supply chains and towards circularity (e.g. Goldenman *et al.* 2017). At the international level the implementation of chemicals and waste conventions, and of the SAICM CiP Programme, provide drivers for meeting CiP Programme objectives and for information sharing. In addition, the OECD has compiled techniques to estimate releases of chemicals from products to help address "a lack of product use related information in PRTRs" (OECD 2017a). The draft report of the independent evaluation of the Strategic Approach 2006-2015 recognized some success in the implementation of the CiP EPI (SAICM Secretariat 2018). At the same time, the CiP Programme has seen only limited activities by stakeholders to share their actions globally.



Opportunities for standardized systems. Stakeholders have expressed an interest in, and commenced actions to develop, harmonized standards to reduce individual communication efforts, such as collection and sharing of material data for articles across sectors (Goldenman *et al.* 2017; Stringer 2018). Given the interlinkages of supply chains across sectors, such standards would reduce transactions costs significantly. Harmonization may include, for example, shared lists of RSLs, pooled resources, and standardized formats for collecting, managing, reporting and communicating CiP information. Sector-specific discussions and solutions are also needed in this context. Industry associations are likely to be well-placed to support these efforts. A successful example of this approach is the IMDS used by the automotive industry (UNEP 2011).

*Handling confidential business information*: In balancing confidential business information with stakeholders' right-to-know, one way to handle this information is through non-disclosure agreements, either directly between business partners or through a third party that gathers relevant information and provides proof of compliance without revealing confidential business information (UNEP 2011). The SAICM OPS acknowledges the need to ensure that confidential commercial and industrial information and knowledge are protected, while noting that information on chemicals relating to the health and safety of humans and the environment shall not be regarded as confidential.

*Getting the information to end-of-life users*: CiP information is relevant for all stages of the supply chain, including for the recycling and waste handling industry to better understand potential exposure and to consider whether the recycling of relevant products could (re) introduce contaminants into the supply chain (Goldenman *et al.* 2017). Given current gaps, opportunities exist for improved communication between producers and the waste and recycling sector (Kogg and Thidell 2010). The European Chemicals Agency (ECHA) will establish a new database on the presence of substances of very high concern in articles, primarily for use by waste treatment operators and consumers (ECHA 2018).

*Legislative gaps and lack of enforcement*: The development of material declaration requirements concerning toxic substances along the supply chain could ensure better flow of CIP information (UNEP 2011). While some regulations exist, legal information on chemicals in products cover only a few sectors, such as the electronics and the automotive industries, and to a limited extent (Goldenman *et al.* 2017). Equally relevant, enforcement is needed to ensure that stakeholders comply with these regulations. Increased efforts to monitor compliance through random tests and control measures could increase compliance rates and stimulate increased substitution actions and information provision (Kogg and Thidell 2010; Goldenman *et al.* 2017).

*Awareness-raising and capacity building*: Most of the existing CiP information systems have been initiated in developed countries and therefore often do not take into account conditions present in low- and middle-income countries (Scruggs, Nimpuno and Moore 2016). Scaling up education and capacity building could complement legislative requirements and help stakeholders manage the collection and transmission of CiP information according to the different information requirements they have to meet. Moreover, experiences and lessons learned from the implementation of CiP systems in developing countries may be of value in developed countries, particularly for developing country industries seeking to enter the international market.

### Potential measures to further address CiP

Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further address CiP:

*Strengthening global CiP approaches:*

- Explore harmonized cross-sectoral CiP information sharing protocols to collect, manage, report and communicate chemicals in products information (e.g. shared restricted substance lists [RSLs], standardized information management systems) across supply chains in each sector, including the waste sector.

- Include CiP elements in extended producer responsibility policies.
- Integrate toxicity considerations into life cycle analysis for products and increase awareness of product designers of chemical selection consequences along the supply chain to advance design of safer products and circularity.
- Develop criteria for information disclosure and protecting confidentiality where reasonable.
- Strengthen capacities to estimate releases from products (e.g. through Pollutant Release and Transfer Registers (PRTRs).
- Scale up and replicate non-disclosure agreement projects, consumer awareness projects and certification programmes.
- Explore how the use of emerging digital technologies can enable information sharing along the value chain while protecting confidential data (e.g. Blockchain).

*Further develop the SAICM CiP Programme:*

- Identify new partnerships in the priority categories (toys, textiles, construction products, electronics) (e.g. link electronics, occupational health and safety, and waste treatment).
- Develop guidance on integrating CiP objectives within corporate sustainability reporting.
- Work with other bodies to stimulate development of harmonized protocols to collect, manage, report and communicate CIP information.
- Coordinate the development of digital applications (in tracing chemical information on toxicity, eco-toxicity, resource demand (energy and materials) and transport of chemicals throughout the supply chain.
- Take action to share lessons learned, and to scale up education and capacity building, in developing countries and countries with economies in transition.

### 4.3.2 Per- and polyfluoroalkyl substances (PFASs) and the transition to safer alternatives

#### Introduction

PFASs are a family of thousands of chemicals widely used in industrial and consumer applications since the 1950s, most often where extremely low surface energy or surface tension and/or durable water and oil repellency is needed (e.g. in various fire-fighting foams and for surface treatment of textiles). Some PFASs have been produced and used on a scale of thousands of tonnes or greater annually (Prevedouros *et al.* 2006; Wang *et al.* 2017a).

Numerous efforts have been made to assess the risks associated with PFASs, with a focus on so-called “long-chain” perfluoroalkyl acids.[2] Consequently, long-chain PFASs have been widely recognized as contaminants of high global concern due to their high persistence, bioaccumulation potential, toxicity, and ubiquitous distribution in the global environment, biota and humans (OECD 2013). In two recent cases, chemical companies paid settlements in the range of hundreds of millions of US dollars as a result of injuries caused through large releases of PFASs to local water supplies (Stegon 2017; State of Minnesota 2018). Widespread efforts are now under way to phase out and replace long-chain PFASs with alternatives. In 2009, at the second session of the ICCM, “Perfluorinated chemicals and the transition to safer alternatives” was recognized as an issue of concern under SAICM.

#### State of the issue

The OECD maintains a global database of PFASs (OECD 2018b). To date, more than 4,700

2 PFCAs, $C_nF_{2n}COOH$, $n \geq 7$), perfluoroalkane sulphonic acids (PFSAs, $C_nF_{2n}SO_3H$, $n \geq 6$) and their major precursors.

Chemical Abstracts Service (CAS) numbers have been identified which can be associated with a large variety of PFASs that (may) have been on the global market and in the environment (Figure 4.7). Meanwhile, a complete account is still lacking due to an absence of transparent, quantitative information on the production and use of PFASs, and lack of analytical standards in the public domain (Wang *et al.* 2017b; OECD 2018b). While substantial progress has been made in understanding the hazards, exposure, risks and treatment of some long-chain PFASs,

**Figure 4.7** **Schematic overview of the structure categories of identified PFASs (adapted from OECD 2018b, p. 17)**

**Commonly recognized per- and polyfluoroalkyl substances (PFASs)**

- PFASs
  - perfluoroalkyl/ - per- and polyfluoroalkylether acids (PFAAs)
    - perfluoroalkyl carboxylic acids (PFCAs), $C_nF_{2n+1}$-COOH
    - perfluoroalkane sulfonic acids (PFSAs), $C_nF_{2n+1}$-$SO_3H$
    - perfluoroalkyl phosphonic acids (PFPAs), $C_nF_{2n+1}$-$PO_3H_2$
    - perfluoroalkyl phosphinic acids (PFPiAs), $(C_nF_{2n+1})(C_mF_{2m+1})$-$PO_2H$
    - per- and polyfluoroether carboxylic acids (PFECAs), e.g. $C_2F_5OC_2F_4OCF_2COOH$
    - per- and polyfluoroether sulfonic acids (PFESAs), e.g. $C_6F_{13}OCF_2CF_2SO_3H$
  - PFAA precursors
    - perfluoroalkane sulfonyl/carbonyl fluorides (PASFs) (PASFs/PACFs) $C_nF_{2n+1}SO_2F/C_nF_{2n+1}CO_2F$ → PASF/PACF-based substances $C_nF_{2n+1}SO_2$-R / $C_nF_{2n+1}CO_2$-R
      - side-chain fluorinated polymers e.g. (meth)acrylate, urethane or oxetane polymers
      - non-polymers R = NH, $NHCH_2CH_2OH$, etc.
    - perfluoroalkyl iodides (PFAIs) $C_nF_{2n+1}I$ → Fluorotelomer iodides (FTIs) $C_nF_{2n+1}CH_2CH_2$ → Fluorotelomer based substances $C_nF_{2n+1}CH_2CH_2$-R
      - side-chain fluorinated polymer e.g. (meth) acrylate, urethane or oxetane polymers
      - non-polymers R = NH, $NHCH_2CH_2OH$, etc.
    - Per- and polyfluoroether-based substances, e.g. $C_4F_9OC_2F_4OC_2F_4OCF_2$-$CH_2OH$ (CAS number 317817-24-6)
  - other PFASs
    - fluoropolyethers (FPs) — polytetrafluoroethylene (PTFE), polyvinylidene fluoride (PVDF), fluorinated ethylene propylene (FEP), perfluoroalkoxyl polymer (PFA), polyvinyl fluoride (PVF), etc.
    - perfluoropolyethers (PFPEs), e.g. $HOCH_2O$-$(C_mF_{2m}O)_n$-$CH_2OH$

**Other highly fluorinated substances that match the definition of PFASs, but have not yet been commonly regarded as PFASs**

perfluorinated alkanes ($C_nF_{2n+2}$)

perfluorinated alkenes ($C_nF_{2n}$) and their derivatives (e.g. $[(CF_3)_2CF]_2C$=$(CF_3)(OC_6H_4SO_3Na)$, CAS number 70829-87-7)

perfluoroalkyl alcohols ($C_nF_{2n+1}OH$; e.g. $(CF_3)_3C$-OH, CAS number 2378-02-1), perfluoroalkyl ketones (e.g. $C_nF_{2n+1}C(O)C_mF_{2m+1}$) and semi-fluorinated ketones (e.g. $C_nF_{2n+1}C(O)C_mH_{2m+1}$)

side-chain fluorinated aromatics, e.g. $C_nF_{2n+1}$-aromatic rings

perfluoroalkyl phosphonic acids (PFPAs), $C_nF_{2n+1}$-$PO_3H_2$

some hydrofluorocarbons (HFCs, e.g. $C_nF_{2n+1}$-$C_mH_{2m+1}$), hydrofluoroethers (HFEs, e.g. $C_nF_{2n+1}OC_mH_{2m+1}$) and hydrofluorooelfins (HFOs, e.g. $C_nF_{2n+1}$-CH=$CH_2$) that have a perfluoroalkyl chain of certain length other PFASs and non-fluorinated alternatives have received limited attention (Holmquist *et al.* 2016; Wang *et al.* 2017b). Information on the hazards of many non-fluorinated alternatives to PFASs is lacking (Holmquist *et al.* 2016); hence scientists, regulators and civil society organizations are increasingly calling for effective and efficient assessment and management of overlooked and novel PFASs and for research on non-fluorinated alternatives to PFASs (Scheringer *et al.* 2014; Blum *et al.* 2015; Borg *et al.* 2017; Wang *et al.* 2017b; Brendel *et al.* 2018; Ritscher *et al.* 2018).

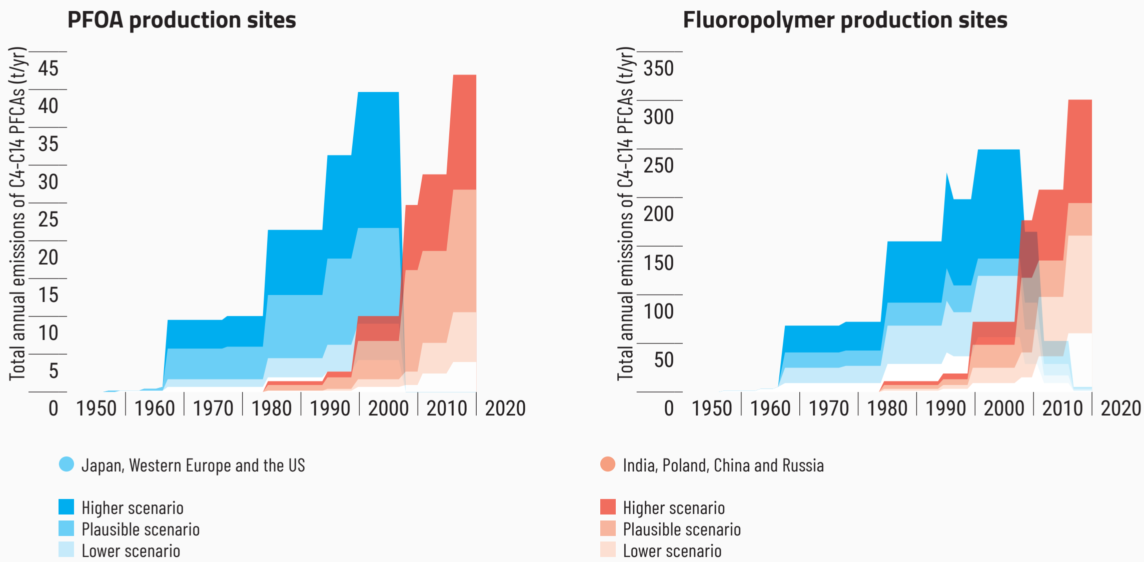
Recent studies suggest that many overlooked and novel PFASs possess some of the same properties as structurally similar long-chain PFASs, including toxicity, high persistence, mobility in the environment and modes of action (Scheringer *et al.* 2014; Birnbaum and Grandjean 2015; Blum *et al.* 2015; Wang *et al.* 2015; Wang *et al.* 2016; Gomis *et al.* 2018). In addition, recent studies show that many PFASs, particularly those with short perfluoroalkyl(ether) chains, cannot be removed from contaminated water by using conventional and many advanced treatment technologies (e.g. Sun *et al.* 2016; Xiao *et al.* 2017; Ross *et al.* 2018).

Most producers in developed countries and in some in developing countries have phased out long-chain PFASs and moved to chemical and non-chemical alternatives (OECD 2015; POPRC 2016). The resulting market gap has been filled by other producers in developing countries and economies in transition (Wang *et al.* 2014) (Figure 4.8), leading to a number of developments with respect to human and environmental exposure in different regions (Wang *et al.* 2014; Land *et al.* 2018): While perfluorooctanesulfonic acid (PFOS) and perfluoroctanoic acid (PFOA) show clear trends regarding concentrations in humans (declining in North America and Europe, but increasing in China), no clear pattern can be identified for other substances (Land *et al.* 2018).

## Policy developments and considerations

PFOS, its salts, and perfluorooctanesulfonyl fluoride (POSF) are listed in the Stockholm Convention under Annex B on the restriction

**Figure 4.8** **Estimated annual releases of PFCAs from PFOA production sites (left) and fluoropolymer production sites (right) in the United States, Western Europe and Japan (blue), as well as in China, Russia, Poland and India (orange) (t/yr), 1951-2015 (adapted from Wang *et al.* 2014, p. 19)**




Reprinted with permission from Elsevier.

PFCAs: perfluorinated carboxylic acids; PFOA: perfluorooctanoic acid of production, use, import and export. PFOA, perfluorohexanesulfonic acid (PFHxS) and related substances are at different stages of the evaluation process for listing. International efforts to address some long-chain PFASs and to transition to safer alternatives are being complemented by initiatives in various countries. Examples of regulatory actions taken on PFOA include those in the EU, Canada and Norway (Norwegian Environment Agency 2013; Government of Canada 2017a; EC 2017b). Moreover, PFHxS has been recognized as a substance of very high concern. In China a research and development project on alternatives to PFOS in certain applications has been initiated, among other actions (OECD 2015). Moreover, the US EPA launched a voluntary PFOA Stewardship Program in 2006 aimed at eliminating emissions and product content levels of long-chain PFASs by end of 2015 (US EPA 2018). Existing efforts largely follow a chemical-by-chemical management approach for the large family of PFASs, which has been described as requiring significant time and resources (Cousins *et al.* 2016; Wang *et al.* 2017b).

Significant efforts have also emerged whose purpose is to raise awareness and initiate actions on PFASs other than long-chain PFASs (Borg *et al.* 2017; ECHA 2017; Australian Department of Health 2018a; Brendel *et al.* 2018). New concept(s) are emerging, such as the persistent, mobile and toxic (PMT) concept (Neumann and Schliebner 2017). Moreover, since 2002 there has been a trend among global manufacturers to replace long-chain PFASs with short-chain or non-fluorinated products (OECD 2013). Several furniture retailers, fast food companies, food packaging manufacturers and apparel companies have taken a precautionary approach to either phase out or restrict the use of certain PFASs in their product lines (Cobbing, Campione and Kopp 2017; IKEA 2017; Chiang, Cox and Levin 2018; Gore-Tex 2018; Bergans n.d.). Some non-fluorinated alternatives have been developed by major PFAS producers in several applications including fluoropolymer (Chemours 2016) and textile finishes (Chemours 2018). Substantial progress has also been made in the management of downstream PFAS contamination (Interstate Technology and Regulatory Council 2017).

#### Potential measures to further address PFASs

- Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further address PFASs:
- Ensure that PFASs already identified as concerns are adequately managed.
- Generate further knowledge and advance international action on short-chain PFASs and non-fluorinated alternatives.
- Develop approach(es) to assess and manage PFASs and alternatives, including the chemical grouping approach and the differentiation between essential and non-essential uses, and gather additional data to conduct assessments.
- Scale up development of alternatives to PFASs, including nonfluorinated alternatives, for PFASs in currently essential uses where no alternatives are available.
- Support scientific efforts to assess alternatives in order to determine the safety of both short-chain PFASs and non-fluorinated alternatives; where sufficient evidence is available, consider the development of a "white" list of PFASs that are preferable alternatives.
- Strengthen the engagement of downstream industrial users and retailers to complement regulatory efforts and enhance the capacity of wastewater treatment plants.
- Enhance information exchange and cooperative research, to fill knowledge gaps and ensure that basic and consistent information on all PFASs as well as potential alternatives is available.

### 4.3.3 Environmentally persistent pharmaceutical pollutants

#### Introduction

Pharmaceuticals are indispensable for human and animal health. However, certain pharmaceuticals may cause undesired adverse effects, including endangerment of certain species of vultures, endocrine disruption such as reproductive failures in fish, and the development of antimicrobial resistance due to the wide use of antibacterial agents in human and veterinary medicine (Green *et al.* 2004; Kümmerer 2004; Oaks *et al.* 2004; Santos *et al.* 2010; BIO Intelligence Service 2013; Berkner *et al.* 2014). Pharmaceuticals designed to be slowly degradable or even non-degradable present a special risk when they enter, persist or disseminate in the environment. Such substances are referred to environmentally persistent pharmaceutical pollutants (EPPPs) (SAICM Secretariat 2015c). There are also so-called "pseudo-persistent pharmaceutical pollutants", which are degradable although continuous emissions to the environment can lead to their constant environmental presence (Daughton 2002).

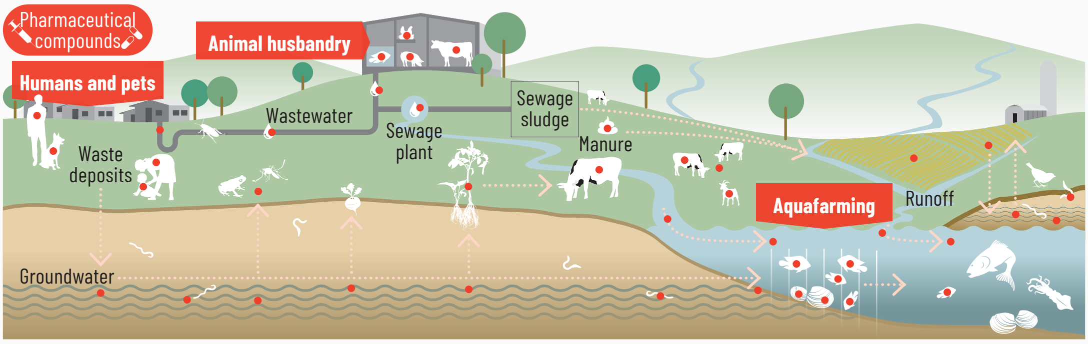
Dozens of new pharmaceuticals are placed on the market every year, with more than 7,000 compounds currently under development (IFPMA 2017). Due to their increasing use and following increasing attention in both the scientific community and public media, policymakers have initiated various actions to address pharmaceuticals in the environment (Boxall *et al.* 2012; Beek *et al.* 2016a, Williams *et al.* 2016, Blair, Zimny-Schmitt and Rudd 2017). As a significant milestone, EPPPs were recognized as an emerging policy issue (EPI) at the fourth session of the ICCM in 2015 (SAICM Secretariat 2015c). The WHO (2014) has described antimicrobial resistance as a growing public health threat and warned about a post-antibiotic era in which common infections and minor injuries may be fatal.

## State of the issue

Pharmaceuticals, including antibiotics, and their metabolites can enter the environment through a variety of pathways, including manufacturing sites, untreated wastewater from households and hospitals, wastewater treatment plants, and municipal waste streams, animal husbandry, sewage sludge and aquafarming (Kümmerer 2009; Monteiro 2010; Lapworth *et al.* 2012; Rastogi *et al.* 2015; Haiß *et al.* 2016; Lübbert *et al.* 2017; Kümmerer *et al.* 2018; Kümmerer *et al.* 2019). Figure 4.9 shows pathways of antibiotics in the environment (Berkner *et al.* 2014) (antimicrobial resistance is further discussed in Part I, Ch. 7). Understanding the contribution of each emission source is a complex endeavour, which varies across regions and pharmaceuticals. Several

© FAO/Domingo Caro, antibiotics use in animal husbandry

**Figure 4.9** **Pathways of antibiotics for human and veterinary use in the environment (adapted from Berkner, Konradi and Schonfeld 2014)**






studies suggest that municipal wastewater is the main emission source for human pharmaceuticals globally (Heberer and Feldmann 2005; Verlicchi, Galletti and Masotti 2010; Verlicchi *et al.* 2010; Boxall *et al.* 2012; Beek *et al.* 2016a). Veterinary pharmaceuticals are found in manure, dung and airborne dust and bioaerosols in the vicinity of livestock farming (Klatte, Schaefer and Hempel 2017; WHO 2017b).

A wide range of treatment techniques have been developed to remove pharmaceutical pollutants in the aquatic phase. However, the removal efficiency varies considerably and no single technique has been found to remove all relevant pollutants from wastewater (Hollender *et al.* 2009; Behera *et al.* 2011; Melvin and Leusch 2016). Hundreds of substances have been detected in countries in all regions and across different environmental media (SAICM Secretariat 2015c; Beek *et al.* 2016a, Beek *et al.* 2016b). Transformation products, including as a result of effluent treatment (Boix *et al.* 2016), may have higher toxicity and a higher potential for accumulation than the parent compound (Kümmerer 2009). Higher concentrations of pharmaceutical pollutants have been found in lower-income countries, possibly due to lack of wastewater treatment infrastructure (Segura *et al.* 2015) and lower regulatory standards. Although analytical techniques have been continuously improved, challenges remain and monitoring, especially in developing countries, still lacks coverage and frequency (Buchberger 2011; Puckowski *et al.* 2016; Madikizela, Tavengwa and Chimuka 2017).

## Policy developments and considerations

In a number of developed countries, pharmaceuticals need to be subject to a tiered environmental risk assessment prior to approval, including risk-benefit analysis (US FDA 1998; Bound and Voulvoulis 2004; EC 2004; Küster and Adler 2014). Action focusing specifically on environmentally persistent pharmaceuticals is yet to be initiated. Given the large number of pharmaceuticals detected in the environment, some have suggested prioritizing those pharmaceutical pollutants that may pose the greatest threats. Several prioritization approaches have been developed in academia to support decision-making (Boxall *et al.* 2012; Roos *et al.* 2012; Donnachie, Johnson and Sumpter 2016; Guo *et al.* 2016) (Box 4.3). At the international level, the World Health Assembly, in 2015, endorsed a global action plan to tackle antimicrobial resistance, including antibiotic resistance (WHO 2015).

Efforts with respect to “green/sustainable pharmacy” are also gaining momentum. These efforts aim, among others, to create more easily degradable pharmaceuticals (Lubick 2008). The idea is to consider biodegradability and the characteristics of drugs, with a view to minimizing the excretion of the active ingredients as an important property starting from the early drug

**Box 4.3 Helping doctors to make informed prescription choices**

In the county of Stockholm, Sweden, human pharmaceuticals are assigned a score indicating environmental persistence, bioaccumulation, toxicity and risk. These scores are used to give prescription recommendations for common diseases. Doctors can choose to prescribe more environmentally friendly pharmaceuticals where medically equal alternatives exist. In 2009, 77 per cent of doctors were reported to have adhered to the recommendations (Gunnarsson and Wennmalm 2008; Gustafsson et al. 2011; Stockholm County Council 2014).

design stages (Kümmerer 2009; Kümmerer and Hempel 2010). Studies have demonstrated that biodegradability is not in contradiction with effectiveness (Rastogi *et al.* 2015). In this context, existing pharmaceuticals are also revisited and enhanced in terms of their biodegradability. Moreover, there are initiatives to advance sustainable procurement of pharmaceuticals in order to create an incentive for manufacturers to strive towards the production of more "green" products, as well as to integrate environmental criteria into manufacturing practices (SAICM Secretariat 2015c).

### Potential measures to further address EPPPs

Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further address environmentally persistent pharmaceutical pollutants (EPPPs):

- Strengthen regulatory requirements and capacities for waste treatment and management, including effluent standards, implementation of disposal and take-back programmes, and adherence to best available techniques and best environmental practices.
- Provide incentive structures to incentivize green and sustainable pharmacy for human and veterinary use, including through sustainable procurement and other innovative schemes.
- At the international level, establish a clear definition and identification criteria for EPPPs, explore the potential of prioritization approaches, and consider the potential relevance of pseudo-persistent pharmaceutical pollutants.
- Implement the WHO global action plan on antimicrobial resistance and WHO Guidelines on the use of medically important antimicrobials in food-producing animals.
- Continue efforts to fill knowledge gaps and share information globally regarding the behaviour, fate, occurrence and effects of pharmaceuticals in the environment, including by upscaling the monitoring of pharmaceuticals in the environment.
- Ensure that relevant interventions address the whole value chain, including research and development, production, prescription and use, and treatment and disposal.
- Enhance the training of doctors and medical staff to help them make informed prescription choices and improve hygienic standards in hospitals while ensuring adequate health control.

## 4.4 Working towards further developing the science and information sharing

### 4.4.1 Nanotechnology and manufactured nanomaterials

#### Introduction

Nanotechnology includes the manufacture, use and manipulation of materials at the nano scale (CIEL 2014). While there is no internationally agreed definition, nanomaterials have been described as in the size range of 1 to 100 nanometres (EC 2011b; International Organization for Standardization [ISO] 2017). The global nanotechnology market is expected to grow at an annual rate of around 17 per cent between 2017 and 2024, when it has been estimated to reach US dollars 125 billion (Research and Markets 2018). Manufactured nanomaterials are now used in many industry applications and consumer products, providing important benefits in areas such as medicine and environmental management.

Despite multiple benefits associated with the technology, concerns have emerged regarding potential risks posed by manufactured nanomaterials to human health and the environment (Jones *et al.* 2017; WHO 2017c). In light of these concerns "Nanotechnology and manufactured nanomaterials" was designated an emerging policy issue at the second session of the ICCM in 2009. Stakeholders stressed the need to close knowledge gaps; to understand, avoid, reduce and manage risks; and to review the methods used for testing and assessing safety (SAICM Secretariat 2009b).

### State of the issue

Consumers may be exposed to nanomaterials via a wide range of products, including food packaging, textiles and personal care products, and workplace exposure to nanoparticles may occur in various types of industries (Nowack *et al.* 2012; Ding *et al.* 2017). Their small size gives nanoparticles properties that may allow for increased penetration of biological and environmental barriers, as well as increased reactivity, making them potentially a more effective source of exposure compared to bulk materials (Hartemann *et al.* 2015; SCENIHR 2009). Potentially adverse effects, including cardiovascular and pulmonary disease, have been identified for a number of manufactured nanomaterials (Gwinn and Vallyathan 2006; Schulte *et al.* 2016; WHO 2017c).

As regards releases to the environment, while in many applications nanoparticles are not present as freely dispersed particles, large fractions may go to landfills, soils and sediments at the end of the life cycle, and smaller fractions to water, and air (Keller *et al.* 2013). Nanopesticides may also be a potential source of significant environmental releases (Khot *et al.* 2012; Kah *et al.* 2013; Kookana *et al.* 2014). Depending on the product lifetime, large stocks may build up from which nanoparticles can be released over long periods of time (Song *et al.* 2017; *Sun et al.* 2017). Once released to the environment, nanomaterials may undergo many transformations, potentially altering their fate, transport and toxicity (Lowry *et al.* 2012). Most nanomaterials do not undergo biological degradation and can therefore persist in the environment (Schwirn and Völker 2016).

Scientific research into nanomaterials and their properties has strongly increased since the 1980s. While much progress has been made in closing knowledge gaps, methods and findings are still often fragmented (Krug 2014; Maynard and Aitken 2016). So far, evidence of nano-specific hazards seems to be lacking (Donaldson and Poland 2013; Dekkers *et al.* 2016) although discussions are ongoing (Lynch, Feitshans and Kendall 2015). There is still a paucity of precise information on releases, fate and transport, concentrations, exposure and effects of nanomaterials (Klaine *et al.* 2008; Montaño *et al.* 2014; Vance *et al.* 2015; Hansen *et al.* 2016; Hansen 2017; Praetorius *et al.* 2017; WHO 2017c) (See Box 4.4).

### Policy developments and considerations

The regulatory approach in the United States includes an information-gathering rule for new and existing nanomaterials in commerce, as well as premanufacture notifications for new nanomaterials (US EPA 2017a). The nanotech initiative of the US-Canada Regulatory Cooperation Council identified common principles for the regulation of nanomaterials to help ensure consistency for industry and consumers in both countries (Government of Canada 2017b). Provisions for specific labelling obligations are in place in the EU for cosmetic products, food and biocides containing nanomaterials (EC 2009b; EC 2011c; EC 2012b). In 2013 the OECD adopted a legal instrument (a Recommendation of the OECD Council) which recommends the application of existing chemical regulatory frameworks when managing the safety of nanomaterials, while recognizing that some Guidelines may need to

**Box 4.4 First standardized test method specifically for nanomaterials adopted by the OECD**

In 2017 the OECD adopted its first Test Guideline describing a test procedure for obtaining information on the dispersion stability of manufactured nanomaterials in simulated environmental media (OECD 2017b). This has been described as an important element for the adaptation of nano-specific requirements for environmental risk assessment (Schwirn and Völker 2016; UBA 2017). In addition, two existing Test Guidelines for inhalation toxicity studies have been updated to allow for the determination the toxicity of inhaled nanomaterials (OECD 2018c; OECD 2018d). Further OECD Test Guidelines and Guidance Documents for the testing of nanomaterials are in progress or being planned.

be adapted to take into account the specific properties of nanomaterials (OECD 2017c).

More recently in the EU, a proposed amendment under REACH would introduce the overarching principle that each nanoform or set of similar nanoform is treated as if it were a separate chemical substance, requiring specific hazard, exposure and risk assessments (EC 2017c). At the global level, the applicability of the Globally Harmonized System of Classification and Labelling (GHS) criteria for nanomaterials is currently being reviewed and the WHO is already advancing classification exercises in the area of workers' health (WHO 2017d). Nanomaterials are also receiving increasing attention in developing countries, however limited regulatory action has been identified to date (Karim *et al.* 2015; Karunaratne 2015; Jain *et al.* 2018; Borges *et al.* 2018).

### Potential measures to further address nanotechnology and manufactured nanomaterials

Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further address nanotechnology and manufactured nanomaterials:

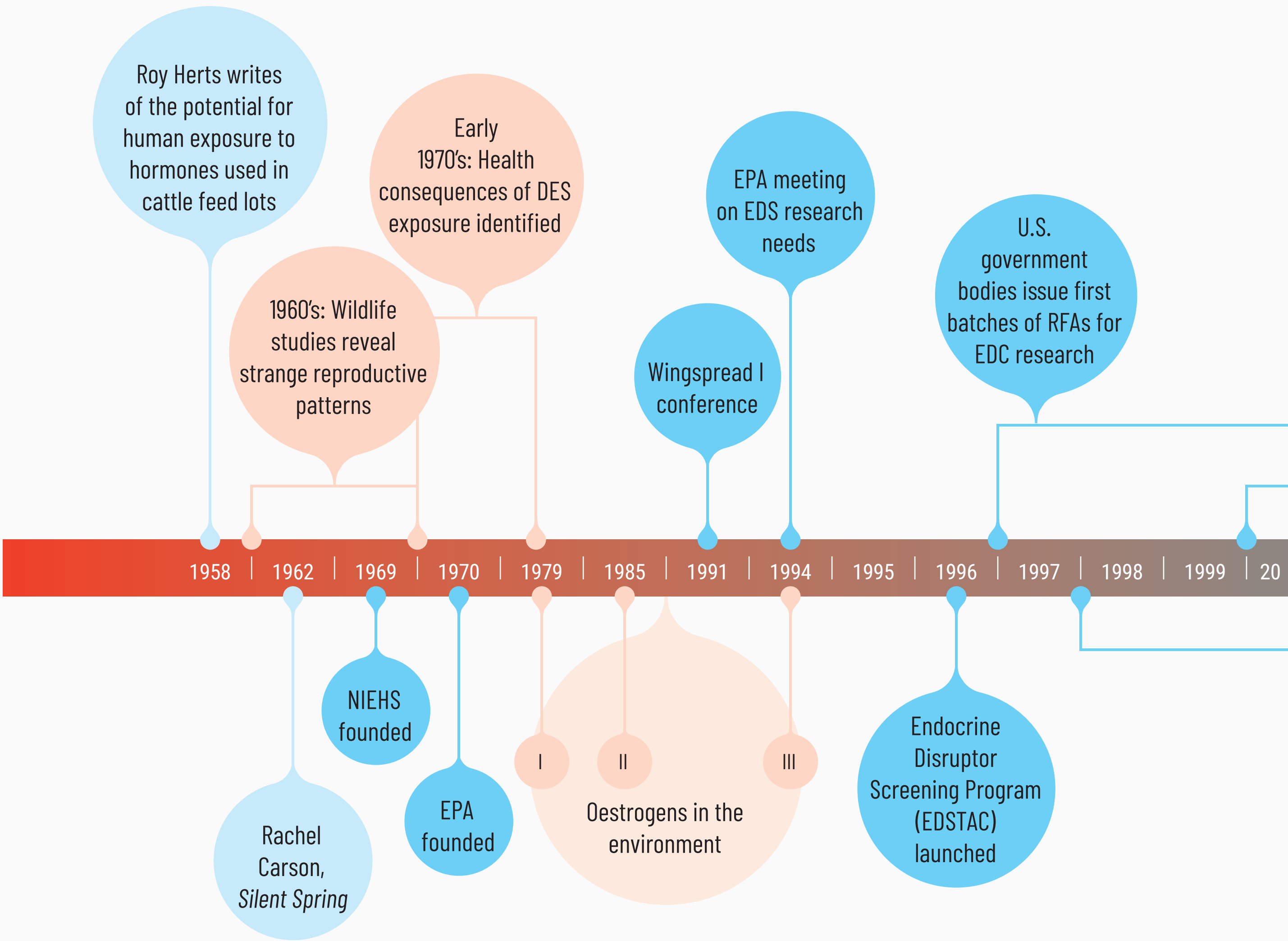
- Enable systematic assessment of the risks of manufactured nanomaterials by further developing standardized tests.
- At the international level, further harmonize methods to facilitate comparison and reliability of data.
- Take global action to enhance hazard communication by applying the Globally Harmonized System of Classification and Labelling (GHS) to nanomaterials and product labelling schemes.
- Adapt regular data requirements to take into account the properties of nanomaterials and facilitate hazard and risk assessments.
- Advance regulatory action, including to protect workers and to ensure that legally binding definitions of nanomaterials are consistent and operational.

## 4.4.2 Endocrine-disrupting chemicals

### Introduction

An endocrine disruptor is defined by the WHO/International Programme on Chemical Safety (IPCS) as "an exogenous substance or mixture that alters the function(s) of the endocrine system and consequently causes adverse effects in an intact organism, or its progeny, or (sub) populations". A potential endocrine disruptor is defined as "an exogenous substance or mixture that possesses properties that might be expected to lead to endocrine disruption in an intact organism, or its progeny, or (sub)populations" (WHO 2002). According to the European Commission (2016a), there is consensus on the use of this definition for identifying endocrine disruptors. Known endocrine-disrupting chemicals (EDCs) include, among others, PCB, DDT, PBDE and some phthalates (see also Part II Ch. 5) (Bergman *et al.* 2013; Schug *et al.* 2016; UNEP 2017b).

**Figure 4.10** **Milestones in the development of the EDC field, 1958-2013 (adapted from Schug *et al.* 2016, p. 835)**



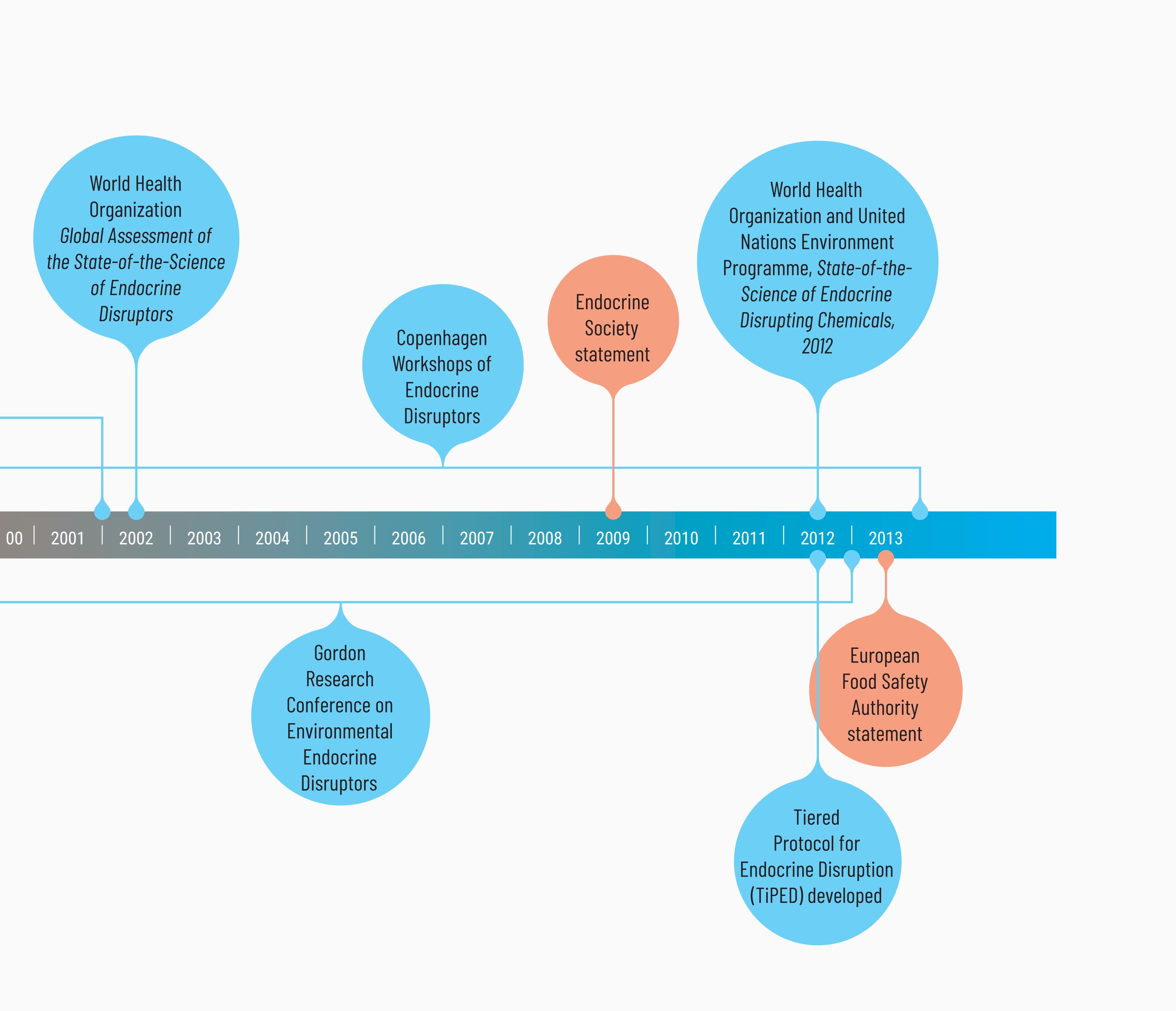



However, no commonly accepted criteria for the identification of EDCs are yet available.

EDCs have become a topic of significant international interest. Substantial efforts have been made over the past decades to develop a better scientific understanding, to identify EDCs and develop scientific approaches to support risk management (Figure 4.10). An important milestone was reached in 2012, when the third session of the ICCM recognized EDCs as an emerging policy issue (EPI).

## State of the issue

While uncertainties remain, a number of laboratory and epidemiological studies have suggested associations between exposure to certain EDCs and adverse effects in humans, including reproductive dysfunctions, cancers, neurodevelopmental disorders, diabetes and metabolic disorders, among others (European Environment Agency 2012; Bergman *et al.* 2013; Gore *et al.* 2015; Kabir, Rahman and Rahman 2015; Schug *et al.* 2016). Some studies also




suggest that certain chemicals have endocrine-disrupting effects on wildlife, including feminization of some species (Lange *et al.* 2009; Flores-Valverde, Horwood and Hill 2010; Annamalai and Namasivayam 2015; Baines *et al.* 2017).

Consensus is emerging on scientific principles for the identification of EDCs (Solecki *et al.* 2017). In this context, it has been noted that "non-specific effects [...] are not considered appropriate for identification of endocrine disruption [and] endocrine activity on its own should not trigger a chemical's identification as an endocrine disruptor". Challenges remain with respect to assessing the impact of EDCs. Areas of uncertainty include low-dose exposure, thresholds and potency (i.e. the dose at which a substance has an effect and whether there a safe threshold exists) and potential non-monotonic dose-response relationships, meaning that severity of effect and exposure are not proportional (EEA 2012; Vandenberg *et al.* 2012; Beausoleil *et al.* 2013; Bergman *et al.* 2013; US EPA 2013; National

Research Council of the National Academies 2014; Lagarde *et al.* 2015; Solecki *et al.* 2017). Moreover, variation in species sensitivities in vulnerability has been noted (Ottinger and Dean 2011). The European Commission (2016a) noted that "four modalities (pathways) are relatively well known and internationally agreed tests exist (the oestrogen, androgen, thyroid and steroidogen modalities) [but] there are other modalities which are not yet well known and for which no internationally agreed tests exist. For these modalities, still under discussion, science is under development and there is no consensus on the extent of evidence (e.g. diabetes) available".

While there are well established general exposure models for humans and wildlife, there is limited knowledge regarding their application during critical periods of development; potential mixture effects; sensitive windows of exposure; and delayed effects (EEA 2012; Beausoleil *et al.* 2013; Bergman *et al.* 2013; US EPA 2013; Menard *et al.* 2014; National Research Council of the National Academies 2014; Lagarde *et al.* 2015; Giulivo *et al.* 2016; Solecki *et al.* 2017).

## Policy developments and considerations

A number of countries have enacted laws and policies, and initiated scientific assessments, to identify and manage EDCs. In the United States the Endocrine Disruptor Screening Program is in place. Potential EDCs are identified and assessed using a two-tier screening programme, followed by a regular risk-based assessment (US EPA 2017b). EDCs are explicitly addressed in the regulatory frameworks on pesticides, drinking water safety and drugs (US EPA 2017c). In the EU several pieces of legislation address EDCs, including the Plant Protection Products Regulation (with a potential amendment currently under discussion), the Biocidal Products Regulation, REACH, the Toy Safety Directive, the Cosmetics Regulation and the Directive on water policy (EC 2000; Scholz 2016). Efforts are ongoing regarding the stepwise establishment of a list of priority substances for further evaluation of their role in endocrine disruption. In a first assessment, clear evidence of endocrine-disrupting activity combined with high exposure concern was noted for 60 substances (EC 2016b). Since then, additional data has been generated in the context of the development of

biocides and plant protection legislation (EC n.d.). In 2017 and 2018, the European Commission adopted scientific criteria for identifying EDCs in biocidal products and plant protection products, respectively (EC 2017d; EC 2018). A guidance document for the implementation of the criteria pursuant to the Biocidal Products Regulation and the Plant Protection Products regulation was also developed and published in 2018 (Andersson *et al.*2018). Efforts to identify EDCs are also ongoing in other countries, including Australia, Brazil, Canada, China and Japan (Ministry of the Environment of Japan 2010; Brazilian Ministry of Foreign Affairs 2017; State Council of China 2016; UNEP 2017c; Australian Department of Health 2018b).

There is lack of systematically gathered data, as few countries have included data requirements for detecting endocrine disruptors in regular data requirements for assessing the hazards and risks of chemicals. Under the auspices of the OECD, efforts are ongoing to further develop standardized test and data interpretation methods to enable a systematic screening and identification of EDCs by regulators. In 2018 new and updated OECD Test Guidelines for chemicals safety testing were adopted, including inclusion of endocrine-related endpoints in two Test Guidelines (OECD 2018e). The OECD Conceptual Framework for Testing and Assessment of Endocrine Disrupters, last revised in 2017, is a guide on available standardized tests available that can provide information on the assessment of endocrine activity and which are grouped in five levels, depending on the information the tests are generating (OECD 2018f). In addition, the OECD has developed a guidance document to interpret the results from the Test Guidelines that were developed (OECD 2018g).

Efforts are also under way to screen chemicals rapidly for bioactivity in several endocrine pathways, as well as to reduce the use of animals in testing through the use of high-throughput screening assays and computational models for evaluation and screening (US EPA 2017d). In addition, stakeholders are further exploring the use of Adverse Outcome Pathways (AOPs), with the aim of providing a plausible mechanistic understanding of the key events linking a mode of action with an adverse outcome caused by an EDC (Ankley *et al.* 2010; Kramer *et al.* 2011; Tollefsen *et al.* 2014; Becker *et al.* 2015; Conolly *et al.* 2017).

## Potential measures to further address EDCs

Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further address endocrine-disrupting chemicals (EDCs):

- Enable systematic screening and identification of EDCs by implementing scientific data requirements and assessment as part of national chemicals legislation.
- At the global level, use and further develop standardized testing methods and criteria to enable identification of EDCs, including to distinguish non-specific effects.
- Continue efforts to reduce remaining uncertainties, including on thresholds, potency, and non-monotonic dose-response relationships.
- Scale up research and epidemiological studies to identify exposures of concern that may lead to health impacts in humans.
- Implement standard data requirements in regular chemicals regulation to improve knowledge on the endocrine-disrupting properties of certain chemicals and multiply available assessments, which could be reused by countries.

# 5/ Other issues where emerging evidence indicates a risk

## Chapter Highlights

In responding to the UNEA-2 mandate, "other issues where emerging evidence indicates a risk" were identified based on a specific set of criteria and to foster knowledge-sharing.

In recent years, assessments and regulatory risk management actions have been taken by public bodies on various chemicals/groups of chemicals not addressed at the international level.

The agreed criteria resulted in the identification of issues for: arsenic, bisphenol A (BPA), glyphosate, cadmium, lead, microbeads, neonicotinoids, organotins, polycyclic aromatic hydrocarbons (PAHs), phthalates and triclosan.

For some of these, concerns had existed for a long time and recent regulatory action has been taken in several countries in light of new evidence on lower thresholds for adverse effects or additional evidence related to specific uses.

In other cases, additional or new evidence has emerged in recent years.

In yet other cases, some countries have taken precautionary action based on existing knowledge.

In 2016 the second United Nations Environment Assembly (UNEA-2) requested the Executive Director of the UN Environment Programme to "ensure that the update of the Global Chemicals Outlook (GCO-II) addresses the issues which have been identified as emerging policy issues by the International Conference on Chemicals Management (ICCM), as well as other issues where emerging evidence indicates a risk to human health and the environment." Emerging policy issues (EPIs) are addressed in the previous chapter (Part II, Ch. 4). "Other issues where emerging evidence indicates a risk to human health and the environment" are addressed in this chapter.

## 5.1 Methodology

### Selection criteria and scope

Several approaches to identifying and categorizing these other issues have been explored. They have included considering broader management issues – which is, to some extent, compatible with the list of potential emerging policy issues (EPIs) (see Part I, Ch. 4) – and identifying actions initiated by public bodies to regulate a chemical (or group of chemicals) or to conduct a full risk assessment or reassessment based on emerging evidence indicating a risk.

The relevance of other international prioritization efforts/initiatives and studies, developed through different approaches and methods, has been taken into account (e.g. the Global Environment Facility [GEF] *Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition* (Bouwman 2012) and the WHO's 10 chemicals of major public health concern (WHO 2018a). As discussed in Part II, Ch. 3, a number of international bodies and mechanisms exist at the international level to identify emerging issues.

In considering various options, it became clear that, without refining the approach, a large and potentially unmanageable number of other issues would emerge (although they would all potentially be compatible with the mandate to address "other issues where emerging evidence indicates a risk"). Therefore, the following approach was identified for the selection criteria (i.e. entry points and necessary conditions for inclusion): At least two countries/regional economic integration organizations have recently (since 2010) undertaken of these two types of action, including at least one regulatory risk management action:

- There has been a regulatory risk management action on a chemical or group of chemicals, based on emerging evidence indicating a risk to human health and the environment.

- A full risk assessment or reassessment action for the same chemical or group of chemicals has been completed or initiated.

Chemicals/groups of chemicals comprehensively covered by existing multilateral environmental agreements,[1] and issues covered by the Strategic Approach to International Chemicals Management (SAICM), are not included. It should furthermore be noted that a number of governments have taken risk assessment or regulatory risk management action prior to 2010, both on chemicals/groups of chemicals identified here as well as one many other chemicals/groups of chemicals.

Through drawing upon various types of action by public bodies in UN Member States, a weight-of-evidence approach is brought to the process. It is important to note that the approach taken does not aim to conduct and deliver an international science-based assessment of specific chemicals or groups of chemicals. Rather, it is meant to facilitate international sharing of knowledge on specific actions recently taken based on emerging evidence indicating a risk. By undertaking a meta-review and drawing attention to existing risk assessment and regulatory risk management action, the objective is to facilitate understanding of issues of potential interest to governments and other stakeholders, which could facilitate future action in other countries or internationally.

For some of the chemicals/groups of chemicals discussed in the following sections, concerns had existed for a long time (e.g. about lead, which continues to be widely used in applications other than paint) recent regulatory action has been taken in several countries in light of new evidence on lower thresholds for adverse effects or additional evidence related to specific uses. In other cases, additional or new evidence has emerged in recent years, prompting regulatory action (e.g. on microbeads). In yet other cases, some countries have taken precautionary action based on existing knowledge.

## Information provided

For each of the "other issues", two to three paragraphs are featured covering the following information:

- basic information about the chemical/group of chemicals;

- areas of use/application and economic information/market developments;

- hazard classification and human health and environmental concerns; and

- risk management/risk assessment action taken by countries.

1 Thus chemicals currently being evaluated under the Stockholm Convention are not considered, nor are chemicals listed under Appendix V of the Rotterdam Convention PIC [prior informed consent] Circular, i.e. chemicals not listed in Annex III of the Convention, but for which the Secretariat has received one notification verified as complete. These chemicals are not considered because knowledge exchange at the international level has already been initiated.

In addition, for each of the "other issues" the following supplementary information is included in a table (see Annex):

- regulatory action taken since 2010;
- (re-)assessment action and reports published and initiated since 2010; and
- possible inclusion in existing prioritization initiatives.

These issues are presented in alphabetical order.

## 5.2 Arsenic – potential risk to health and environment

Arsenic is a naturally occurring element that is widely distributed in the Earth's crust. It is used in wood preservatives, pesticides, batteries and semiconductors, among other purposes (United States Agency for Toxic Substances and Disease Registry [US ATSDR] 2007). Global production has been relatively steady in recent years, at 37,100 tonnes in 2016 (United States Geological Survey [USGS] 2018).

The primary route of arsenic exposure for the general population is via ingestion of food, including fish, rice and dairy products, or of water (IARC 2012a; WHO 2018b). Arsenic is highly toxic in its inorganic form and classified as carcinogenic to humans (IARC 2012a). It has been associated with cardiovascular disease, diabetes, and adverse effects on the nervous, respiratory, immune and endocrine systems (United States National Institute of Environmental and Health Sciences 2014). In the environment arsenic can induce a variety of toxic effects in wildlife (Tokar, Xu and Waalkes 2015). Examples of recent regulatory actions are a restriction on the sale and use of arsenic in anti-fouling, water treatment and wood preservation in Turkey, and new limits on arsenic levels in rice in the EU (see Annex).

## 5.3 Bisphenol A in products – potential risk to health and environment

Bisphenols are a group of synthetic organic compounds primarily used as a building block in the production of polycarbonate plastics and epoxy resins, which are used in a wide variety of products including water bottles, sports equipment, medical devices, household electronics, thermal paper receipts, and food and beverage cans (Carlisle *et al.* 2009; Liao and

© Cgoodwin, Part of the remains of arsenic processing plant, Ottery mine, Tent Hill, NSW. Arsenic compounds can be seen coating the surface of the brickwork CC BY-SA 3.0

Kannan 2011). The global bisphenol A (BPA) market is expected to experience a compound annual growth rate (CAGR) of approximately 6.5 per cent between 2018 and 2023 (Research and Markets 2018).

BPA has been detected in thermal paper at high levels of up to 3-22 g/kg (Mendum *et al.* 2011, Biedermann, Tschudin and Grob 2010) as well as in paper currencies (Liao and Kannan 2011). Polymers degradation is the dominant mechanism responsible for bisphenol releases from products (Mercea 2009). The primary source of exposure to BPA for most people is through food and beverages, by migration from containers (Carlisle *et al.* 2009); 1.4 and 2 times higher levels of daily intakes have been observed for pregnant woment and for children compared to adults (Huang *et al.* 2017). Between 2004 and 2012, median urinary levels of BPA in the US population decreased (US CDC 2017a). The omnipresent body burden to BPA in many population groups has been confirmed in various human biomonitoring studies (Koch *et al.* 2012).

A number of studies provide evidence that BPA is an endocrine disruptor (Rochester and Bolden 2015). Other potential effects, such as adverse behavioral outcomes (Ejaredar *et al.* 2017), obesity and type 2 diabetes (Stojanoska *et al.* 2017; Hwang *et al.* 2018), are under investigation and further research is needed, for example to understand effects on human health at low environmental exposures (US CDC 2017b). BPA may also be a causal agent in cardiovascular diseases, diabetes, metabolic disorders, prostate cancer, and immune system alterations. Bisphenol S, which has been used as an alternative to BPA, has been identified in the literature as a regrettable substitution (see Part III, Ch. 5). In recent years a number of countries in Asia, Europe and North America have banned or restricted the production and sale of some products containing BPA (see Annex).

## 5.4 Glyphosate in agriculture and residential use – potential risk to health and environment

Glyphosate is an organophosphorus compound without anti-cholinesterase activity. It is an active ingredient in herbicide formulations that are widely used for agricultural, forestry, and residential weed control. The glyphosate market has grown rapidly since 1994 and is expected to continue to experience strong growth in the next years (Benbrook 2016; Markets and Markets 2017).

Information on the extent of exposure to glyphosate among various populations is still limited and the need for further research, including to understand temporal trends, has been noted (Gillezeau *et al.* 2019). A study on time trends in glyphosate exposure undertaken in Germany found the data to mirror increasing glyphosate application and suggest possible exposure reduction after 2012 (Conrad *et al.* 2017). The scientific debate regarding adverse potential risks to human health are ongoing. For example, a 2013 study (Chang and Delzell 2016) and a 2016 study (Acquavella *et al.* 2016) reviewing the literature could not find evidence for a causal relationship between glyphosate exposure and Non-Hodgkin lymphoma. According to a 2019 study (Zhang *et al.* 2019), a meta-analysis of human epidemiological studies suggests a compelling link between exposures to glyphosate-based herbicides and increased risk for Non-Hodgkin lymphoma in humans.

A number of bodies have assessed glyphosate, in particular with a view to potential cancer risk to humans. In 2015 the International Agency for Research on Cancer (IARC) classified glyphosate as "probably carcinogenic to humans" (IARC 2015); however, this is a hazard identification. Later in 2015, the European Food Safety Authority (EFSA) concluded that "the substance is unlikely to be genotoxic (i.e. damaging to DNA) or to pose a carcinogenic threat to humans" (EFSA 2015). In 2016 the ECHA Committee for Risk Assessment (RAC) found that glyphosate causes serious eye damage and is toxic to aquatic life with long-lasting effects; however, the RAC did not find evidence to classify glyphosate for specific target organ toxicity or as a carcinogen, as a mutagen, or for reproductive toxicity (ECHA 2017). Also in 2016, FAO/WHO Joint Meeting on Pesticide Residues (JMPR) concluded that "glyphosate is unlikely to pose a carcinogenic risk to humans from exposure through the diet" (FAO and WHO 2016). In 2017 Health Canada concluded that registered glyphosate products do not present unacceptable risks to human health or the environment, or present carcinogenic risk to humans, when used according to revised use directions (Health Canada 2017a). According to Health Canada, "no pesticide regulatory authority in the world currently considers glyphosate to be a cancer risk to humans at the levels at which humans are currently exposed" (Health Canada 2019). Some countries have taken regulatory and/or assessment actions on glyphosates (see Annex).

## 5.5 Cadmium – potential risk to health and environment

Cadmium is a soft, silver-white metal naturally found in the Earth's crust. The largest use of cadmium is in batteries, predominantly rechargeable nickel-cadmium batteries. It is also widely used in pigments, coatings and electroplating (US ATSDR 2012). Global production, most of which is located in the Asia-Pacific region, has increased since 2010, reaching 23,900 tonnes in 2016 (USGS 2018). An important application driving the growth of cadmium production is solar cells (Transparency Market Research 2015; World Energy Council 2016).

The non-smoking general population is exposed to cadmium primarily via ingestion of food (IARC 2012b). Several studies have found cadmium (at levels up to 188 ppm) in plastic toys sold in various countries (Kumar and Pastore 2007; Omolaoye *et al.* 2010; Korfali 2013). Cadmium containing waste also poses challenges (Friege, Zeschmar-Lahl and Borgmann 2018). Cadmium is classified as carcinogenic to humans (IARC 2012b). Exposure to cadmium mainly affects kidney function and has, among others, been linked to reduced lung function as well as damage to bones, with children particularly at risk (US ASTDR 2012). Adverse effects on animals and plants have also been identified (Kumar and Singh 2010; Gallego *et al.* 2012). The UNECE Protocol on Heavy Metals under the Convention on Long Range Transboundary Air Pollution addresses cadmium among other heavy metals. In recent years a number of regulatory agencies, including in China, the Eurasian Economic Union (EEU) and the EU, have taken action to restrict the use of cadmium in electrical and electronic equipment, paints and fertilizers (see Annex).

## 5.6 Lead – potential risk to health

Lead is a heavy metal that occurs naturally in the Earth's crust. Historically, important uses of lead and lead compounds have included in gasoline, pipes and many other products. Lead continues to be used in paints, toys, furniture, ammunition and batteries, among others. World production of lead in 2017 was 11.3 million tonnes, with lead-acid batteries reportedly accounting for around 80 per cent of consumption (International Lead and Zinc Study Group [ILZSG] 2018). Increasing production of electric cars and bicycles is likely to boost demand for lead to be used in batteries during the next couple of years (ILZSG 2018), with this market expected to continue to grow in the medium term (PR Newswire 2018).

Lead levels of up to 1,445 ppm have been found in some toys (Omolaoye, Uzairu and Gimba 2010). People can be exposed to lead through inhalation of lead particles in air, drinking water, eating foods, or swallowing dust or dirt. Children can have higher exposure to lead in dust, soil or object coatings/paints due to frequent hand-to-mouth or object-to-mouth activities (O'Rourke *et al.* 1999). Significant reductions in lead exposure and blood lead concentrations have occurred in many high- and some middle-income countries (Landrigan *et al.* 2018). However, there are still several important pathways of occupational and community exposure, particularly in developing countries, such as lead-glazed pottery, lead pipes and informal recycling of lead-acid batteries. The health effects of exposure to lead include hypertension, renal failure, cardiovascular disease and stroke, especially among workers, while neurodevelopmental toxicity constitutes the most important consequence of lead toxicity in children (Landrigan *et al.* 2018).

According to the WHO, there is no known level of lead exposure that is considered safe (WHO 2018c). Estimates from the Global Burden of Disease (GBD) study indicate that lead was responsible for 0.5 million premature deaths and 9.3 million DALYs in 2015 (GBD 2015 Risk Factors Collaborators 2016). The UNECE Protocol on Heavy Metals under the Convention on Long Range Transboundary Air Pollution addresses lead among other heavy metals. While lead in gasoline has largely been banned across the world and lead in paint is being addressed as an emerging policy issue (EPI) under SAICM (with many countries having taken regulatory action), a number of countries have recently taken further regulatory actions to restrict the use of lead in other products such as jewelry, toys and electronics (see Annex).

## 5.7 Microbeads in personal care products and cosmetics – potential risk to the environment

Microbeads are a type of primary (i.e. intentionally added) microplastics (commonly considered to be micrometre-sized particles less than 5 mm in length) intentionally used in personal care products, other consumer applications, and various industrial applications. (e.g. scrubs, toothpastes) (Environment and Climate Change Canada 2015; United States Food and Drug Administration 2017; United States National Oceanic and Atmospheric Administration 2018). Exfoliating agents, for example, may contain more than 10 per cent microbeads (Brande-Lavridsen n.d.).

Studies show that the majority of microplastics[2] released to the oceans are secondary microplastics originating from the degradation of larger plastic items, in particular textiles and tyres (Boucher and Friot 2017), while microbeads from personal care products and cosmetics represent a relatively small source of microplastics in the environment (Essel *et al.* 2015; UNEP 2016), estimated in one study at 2 per cent (Boucher and Friot 2017). Although modern wastewater treatment plants may capture up to 99 per cent of microplastics (Magnusson and Noren 2014), significant amounts may nevertheless enter waterways, depending on the existence and efficacy of wastewater treatment facilities (Murphy *et al.* 2016; UNEP 2016).

2 While primary microplastics are intentionally added to products, secondary microplastics are generated from the breakdown of larger plastic items. Given the focus on microplastics rather than microbeads (a type of microplastics) in the literature, most of the information provided in this section refers to microplastics.

Aquatic organisms may be exposed to microplastics through direct ingestion, consumption of prey that have ingested the plastics, and dermal exposure (Beaman *et al.* 2016). Humans can be exposed to microplastics through ingestion of contaminated food and drinking water (Crampton 2017). A study found that humans may consume up to 11,000 plastic particles per person per year from shellfish alone (Van Cauwenberghe and Janssen 2014). Given the relatively small share of microplastics in the oceans originating from cosmetics, it is likely that only a small share of exposure can be thus attributed. Hydrophobic chemicals, such as PCBs and DDT, have been found to sorb to microplastics (Nerland *et al.* 2014; Gallo *et al.* 2018; Lassen *et al.* 2018). While evidence suggests this may constitute a relatively minor impact on contaminant exposure compared to other exposure pathways, further research could be warranted (Beaman *et al.* 2016; UNEP 2016; Lassen *et al.* 2018).

Studies have shown various adverse effects on aquatic organisms (Beaman *et al.* 2016; Brande-Lavridsen n.d.). A state of the science summary (Environment and Climate Change Canada 2015) concluded that the continuous release of microbeads may result in long-term effect on biological diversity and ecosystems. The potential risks of microplastics to human health are largely unknown (Crampton 2017). The limited evidence available suggests that microplastics in seafood might not currently represent a substantial health risk, although uncertainties remain (UNEP 2016). Several countries have recently taken regulatory actions to restrict the manufacture, import and sale of microbeads in cosmetics (see Annex).

## 5.8 Neonicotinoids in outdoor agriculture – potential risk to the environment

Neonicotinoids are a class of neuroactive insecticides chemically related to nicotine. Seven neonicotinoid insecticides are on the market, of which imidacloprid is the most widely used (Jeschke *et al.* 2011). Neonicotinoids currently account for 24 per cent of the global market and their use is increasing globally (Duchet, Kraft and Stark 2018). Neonicotinoids are not only used as plant protection products but also as biocides.

A review found "a growing body of evidence demonstrates that persistent, low levels of neonicotinoids can have negative impacts on a wide range of free-living organisms" (Wood and Goulson 2017). Another review of the literature predicts "substantial impacts on biodiversity and ecosystem functioning" from present concentrations of neonicoitnoids (van der Sluijs *et al.* 2015). It has been suggested that effects may differ between honeybees and bumblebees (Rundlöf *et al.* 2015). Several studies have found adverse effects on wild bee populations from exposure to certain neonicotinoids (e.g. Woodcock *et al.* 2016). Further studies found neonicotinoids to be negatively affecting pollinator health under realistic agricultural conditions (Tsvetkov *et al.* 2017; Woodcock *et al.* 2017).

Some have highlighted the difficulties entailed in such assessments, noting the multifactorial nature of bee declines (de Miranda and Nazzi 2017). Efforts are under way to address remaining uncertainties regarding field-realistic conditions (Rortais *et al.* 2017). Despite the significant progress made in recent years in further assessing risks to pollinators, further research is needed, for example to assess risks of multiple stressors (Rortais *et al.* 2017). Moreover, a need for further studies on the potential effects of neonictonids on human health has been suggested (Cimino *et al.* 2017). Extensive assessments have been undertaken by relevant authorities (e.g. Health Canada 2017b). As an example of regulatory action, in 2013 the EU prohibited the use of three neonicotinoids in bee-attractive crops (see Annex).

## 5.9 Organotins as biocides – potential risk to health and environment

Organotins are organic compounds that contain at least one tin-carbon bond. There are four main groups of organotin compounds, which are used in various applications including as biocidal agents in wood preservatives and disinfectants, catalysts, sealants and stabilizers US ASTDR 2005; KEMI 2018). Various uses have been restricted by regulatory agencies, e.g. use as biocidal agents, or banned, e.g. use as antifouling paints on ships. Production of organotins has increased significantly during the past decades (Cole *et al.* 2015).

Organotins have been found in water bodies (e.g. US ASTDR 2005; Deng *et al.* 2018). The organotin compound tributyltin (TBT) is considered among the most hazardous substances released into the marine environment, primarily from use in anti-fouling systems, with levels in some areas posing significant environmental risk (Andersen *et al.* 2010). In addition to occupational exposure, the general population can be exposed to some organotins through ingestion of food and contact with household products containing organotin compounds (Sousa *et al.* 2014; National Pollutant Inventory of Australia 2019). Depending on the compound, exposure to organotins has been reported to cause skin, eye and respiratory irritation, neurological problems, and effects on the immune system (National Pollutant Inventory of Australia 2019; KEMI 2018; Nunes-Silva *et al.* 2018). Adverse effects on animals have also been observed, including endocrine disruption (National Pollutant Inventory of Australia 2019; Puñal de Araújo *et al.* 2018). Examples of recent regulatory action include restriction in China and the EU of the use of anti-fouling systems containing organotin compounds as biocides (see Annex).

## 5.10 Polycyclic aromatic hydrocarbons in products – potential risk to health

Polycyclic aromatic hydrocarbons (PAHs) are a group of more than 100 different chemicals that occur naturally in coal and crude oil, but are also formed as a by-product during the incomplete burning of coal, oil, gas, wood, garbage and other organic substances (US CDC 2017c).

A number of PAHs are classified as carcinogenic, mutagenic and/or toxic for reproduction (CMR) substances. Some are also persistent, bioaccumulative and toxic (PBT) for humans and other organisms, and/or are of concern because they are very persistent and very bioaccumulative. The majority of the PAHs that reach consumers come from tar oils, from specific oils from petroleum refining added as softeners to rubbers and plastics, and the use of industrial soot (carbon black) to dye plastic (UBA 2016). Products that contain PAHs include shoes, bicycle handles and tyres. Following concerns about potential exposure of consumers, several studies have been undertaken to determine emissions of PAHs from products (e.g. Paschke *et al.* 2013; Geiss *et al.* 2017). An example of regulatory action includes the listing of eight PAHs under the EU's REACH restriction list (see Annex).

## 5.11 Phthalates in consumer products – potential effects on health

Phthalates are a group of plasticizers with softening and elastic effects. They are used in products such as vinyl flooring, adhesives, detergents, lubricating oils, automotive plastics, plastic clothing and personal care products (US CDC 2017d). Phthalates accounted for 65 per cent of global consumption of plasticizers in 2017 and are forecast to account for 60 per cent in 2022; consumption of phthalate plasticizers is forecast to grow at an average annual rate of 1.3 per cent during 2017-22, while that of other plasticizers (terephthalates, epoxy, aliphatics, trimellitates, polymerics, benzoates and phosphates) is forecast to grow at an average annual rate of 5.8 per cent in the same period (IHS Markit 2018).

Phthalates are semi-volatile organic compounds (SVOCs) with concentrations of typically 1-40 per cent in flexible vinyl and other products (Biedermann-Brem *et al.* 2008; Goldsmith *et al.* 2014). They possess low volatility, high binding with polymer matrices, and high sorption to dust, indoor surfaces and skin (Hopf *et al.* 2014; Sugino *et al.* 2017). The main human exposure pathway is oral via food (US CDC 2018). Other pathways include direct mouthing (toys), house dust ingestion and dermal gaseous absorption. The highest urine concentrations of phthalates are observed in the young population (Frederiksen *et al.* 2013; Hartmann *et al.* 2018). A study found that less than 3 per cent of surveyed children had a DEHP[3] level exceeding the health-based guidance value (Den Hond *et al.* 2015), which may reflect significant action already taken to reduce its use.

Phthalates are a family of chemical compounds whose characteristics may differ, among others depending on their molecular weight. Some phthalates may be linked to developmental toxicity and adverse effects on reproductive function in humans, as well as in aquatic invertebrates, fish and birds (European Chemicals Bureau 2008; Watkins *et al.* 2017). While a number of phthalates have so far been found to present a limited risk of harm to human health and the environment (Ventrice *et al.* 2013), others have been shown to be plausible endocrine disruptors (e.g. Saillenfait *et al.* 2013; Albert and Jégou 2014).Under REACH, DCHP, DEHP, DIBP, DBP and BBP have been included on the Candidate List of substances of very high concern for authorization due to toxicity for reproduction and endocrine disrupting properties in humans. Restrictions on the use of certain phthalates in some applications have been put in place in recent years in several countries, including in Canada, China, the Republic of Korea and the United States and in the EU. (see Annex).

## 5.12 Triclosan in hygiene products – potential risk to health and environment

Triclosan is an antibacterial and antifungal agent widely used in a variety of products, including cosmetics (e.g. toothpaste and soaps). It can be released to the environment via various pathways and has been detected in surface, ground and drinking water (Dhillon *et al.* 2015). Triclosan biodegrades relatively slowly in freshwater and sediments (Huang *et al.* 2014; Huang *et al.* 2015), but more rapidly by photolysis (Morrall *et al.* 2004; Latch *et al.* 2005; Aranami and Readman 2007).

Exposure to triclosan occurs primarily through the skin or mouth during the use of triclosan-containing products, with only a minor contribution via environmental exposures. A study detected triclosan in the urine of around 75 per cent of people tested in the United States (US CDC 2017e). According to a recent consensus statement by more than 200 scientists and medical professionals (Halden *et al.* 2017), triclosan is toxic to aquatic organisms and is an endocrine disruptor in mammals. Further studies have also found endocrine-disrupting properties and other potential adverse effects (e.g. Wang and Tian 2015; Feng *et al.* 2016; Olaniyan, Mkwetshana and Okoh 2016). However, current levels of use may not pose a major threat to human health (Ena *et al.* 2018). In recent years the United States, Canada and the EU have taken action to restrict the placing on the market and use of triclosan. Canada has also assessed and published its assessment of triclosan under the Canadian Environmental Protection Act (see Annex).

3 Bis(2-ethylhexyl) phthalate.

# 6/ Overall progress towards the 2020 goal: what have we learned?

## Chapter Highlights

Significant progress has been made towards the implementation of the 2020 goal at the national, regional and global level, and by all stakeholders.

Countries have strengthened their capacities for governance, knowledge generation, risk reduction and control of illegal international traffic; however, progress has been uneven.

Progress has been made through multilateral treaties and voluntary international instruments, but gaps in implementation remain.

Opportunities exist to create synergies between different international prioritization processes.

The development of an integrated national programme based on a national profile, as called for by SAICM, could help to strengthen national chemicals management in a coordinated way.

A coherent and impact-based results framework with meaningful indicators could inform national action and capacity development, reporting, and tracking of progress towards the 2020 goal.

This chapter synthesizes the information presented throughout Part II relevant for assessing progress towards the 2020 goal, which has provided an important aspirational goal at all levels and for all stakeholders. While it is difficult to measure progress in a systematic way, given the absence of a comprehensive indicator and reporting framework, it is nevertheless possible to identify certain trends, gaps and opportunities, as well as lessons learned that point towards areas for action.

## 6.1 Progress has been made towards the 2020 goal at the national, regional and global level

### Significant progress has been made towards the five objectives of the SAICM OPS

Many countries have made important headway in enacting laws, creating programmes and implementing policies to achieve the sound management of chemicals and waste. SAICM, with its multi-stakeholder and multi-sector approach, has provided a space and opportunity for government and non-government actors to jointly discuss overarching issues, develop national capacities through the QSP and address emerging policy issues. Governments, the private sector, civil society and other stakeholders, through activities implemented at the local, national, regional and global levels that are complementary to, and often catalysed by, international agreements have made important headway towards the five objectives identified by the OPS:

- *Governance*: Many countries have strengthened their legal and institutional capacities. All regions, although in varying degrees, have made significant progress in recent years with the adoption of overarching chemicals management legislation. Regional institutions have proven an effective tool to strengthen capacity. Often prepared through multi-sectoral and multi-stakeholder collaboration, national profiles have led to the establishment of inter-ministerial committees in a number of countries; led to the production of country baseline information; and facilitated the identification of priority action.

- *Knowledge and information*: Various initiatives have generated data and improved our understanding of the hazards and risks of chemicals of concern. Monitoring systems have been established in many countries and generate important insights. The number of countries implementing the GHS and establishing PRTRs is increasing. Moreover, drawing on existing bodies, science-policy interfaces have been established and strengthened, providing important insights to inform policymaking.

- *Risk reduction*: Regulatory bodies in all regions have taken action to identify, assess and manage a number of priority chemicals of concern, including through bans or restrictions on production and use. Progress in the implementation of legal frameworks, based on the International Code of Conduct on Pesticide Management, is promising. Use of the IOMC tools for risk reduction by stakeholders is increasing, while poisons centres have been established in many countries.

- *Capacity building and financing*: Some progress has been made in mainstreaming chemicals and waste management into national development plans and budgeting. A number of countries have clarified responsibilities between the public and private sector; promoted extended producer responsibility and the internalization of costs by industry; and used fiscal instruments. Industry involvement has also been important in mobilizing resources and has built capacity. As regards external financing, the GEF, the QSP and the Special Programme, as well as bilateral donors, have provided significant resources.

- *Illegal international traffic*: International and national efforts have been ongoing in this field. Various initiatives and agreements at the regional and global level have helped to monitor, reduce and control, to a certain extent, illegal international traffic in chemicals and waste. Countries are cooperating to strengthen regulatory frameworks and build capacity for enforcement to minimize illicit transboundary movement of hazardous waste and to tackle counterfeit products.

### Countries save resources by aligning and harmonizing their policies

Policy learning and alignment is advancing across countries and organization. Many countries are saving resources by aligning their approaches with those of other countries or with internationally agreed guidance. Such guidance includes that developed by the OECD and the WHO. These alignments and harmonization efforts create cost savings through benefiting from progress made in regions with advanced schemes, sharing workloads and facilitating trade. Care should be taken, however, to avoid the human health impacts of manufacturing being shifted through international trade from countries that import goods to those that produce them (Normile 2017).

Numerous success stories showcase how regional institutions and organizations have advanced regulatory harmonization and the development and implementation of policy-oriented action plans across regions. Regional economic and political integration organizations have assumed a particularly prominent role in addressing chemicals and waste in all regions. Close trade relationships create opportunities

for collaboration and harmonization, while maintaining a high standard of protection.

**Specific hazardous chemicals and issues of global concern are successfully addressed through multilateral treaties.**

The international community has taken concerted action, through legally binding treaties, on specific hazardous chemicals and issues of global concern. These treaties have catalysed selected regulatory actions, raised awareness, and succeeded in reducing some exposures to the targeted chemicals and wastes.

The Montreal Protocol has been successful in removing ozone-depleting substances from the atmosphere and protecting the ozone layer, thus avoiding more than 100 million cases of skin cancer; the Basel Convention has successfully strengthened national capacities for the environmentally sound management of hazardous wastes; the Rotterdam Convention has facilitated the exchange of critical information on the trade of hazardous substances; and the production and use of a number of POPs has been restricted or eliminated under the Stockholm Convention. The Minamata Convention on Mercury is also expected to achieve positive results, for example through phasing out the use of mercury in various products.

## 6.2 Significant implementation gaps remain

**Overall progress towards achieving the sound management of chemicals and waste is uneven across countries, regions and actors**

Overall progress is insufficient, pointing to an urgent need to take concerted action to develop basic chemicals management systems in all countries. Developing countries and economies in transition, in particular, still lack basic chemicals and waste management systems. Major gaps remain, for example, in the implementation of the GHS, in the establishment of PRTRs and poisons centres, and in capacities for hazard and risk assessment and risk management. Gaps are particularly prevalent for industrial chemicals and consumer products. Further work is also needed to address pesticides. Moreover, even if regulations for specific chemicals are in place, implementation may pose challenges. Similarly, industry involvement has not been sufficient and challenges have been noted regarding voluntary industry standards and initiatives.

**Provision of financing, technology transfer and technical assistance has not met needs**

Limited progress has been made in integrating chemicals and waste considerations in policymaking. Few success stories are known in which relevant projects were followed up by the allocation of resources from national budgets/resources. Moreover, further efforts are needed in many countries to adopt legislation to internalize costs, as well as to expand the use of economic instruments. External funding has also not matched the need and demand for support, expressed by developing countries and economies in transition, for building basic chemicals and waste management systems. Further action is therefore required to achieve full implementation of the integrated approach with respect to all three components.

### Strengthening integrated national implementation, a priority but challenging

SAICM's quest to support the development of an integrated national programme based on a national profile has sought to align national processes to strengthen chemicals and waste management in a systematic and coordinated way. While valuable work has been undertaken by countries through the development of national chemicals management profiles and plans, there has been a loss of momentum, marked by lack of sufficient funding for developing countries and economies in transition to develop basic capacities. Urho (2018) points out that the lack of one single mechanism for working towards strategically prioritized national action results in an ad-hoc and diffuse approach, which makes it challenging to assess collective progress.

### Implementation gaps remain regarding multilateral treaties and SAICM

The extent to which the objectives of a number of treaties have been achieved is uncertain. Further efforts are needed to achieve full implementation, for example to address gaps in regulatory schemes under the Stockholm Convention and to fully implement the chemicals dimension of the IHR (2015). Given that treaties are designed to address specific chemicals and issues – for example, some mainly focus on specific stages of the life cycle or specific issues (e.g. ILO C174), individual chemicals (e.g. the Minamata Convention) or groups of chemicals (e.g. the Stockholm Convention) – many hazardous substances are beyond their scope. Moreover, not all treaties have been universally ratified. SAICM suffers, among others, from insufficient sectoral engagement; the capacity constraints of national focal points; lack of tools to measure progress; limited financing of activities; and insufficient and uneven advances in substantive areas. Progress has also been slow, modest and uneven in implementing the EPIs, with the exception of lead in paint.

### International prioritization processes are diverse and independent from each other

A diverse set of mechanisms has been established at the international level to identify emerging issues and set priorities for action. This includes processes under chemicals and waste MEAs, the process under SAICM for identifying emerging policy issues and other issues of concern, and regional processes. Moreover, UNEA called for the GCO-II to address "other issues where emerging evidence indicates a risk". These international mechanisms and processes follow different procedures and base the identification and prioritization of chemicals and emerging issues on different criteria. In addition, different organizing frameworks are used, with some targeting specific chemicals/groups of chemicals and others targeting broader management issues. Some of the instruments rely on scientific/technical bodies to provide scientific input to inform identification and prioritization. Synergies may exist among these mechanisms, and there may be value in considering the lessons learned from the respective processes in deliberating options available to identify and prioritize issues under a beyond 2020 framework.

## 6.3 A coherent global results, indicator and reporting framework is lacking

### Reporting rates are not satisfactory

Reporting rates under several agreements are low, particularly among developing countries and economies in transition. In some cases reporting rates exhibit a downward trend (e.g.

under the Stockholm Convention and the Basel Convention). Reporting rates under SAICM have also been disappointing. They show a worrying downward trend, with data lacking particularly from the Africa region. By contrast, reporting compliance has been high or even universal under ILO Conventions, the Montreal Protocol and the IHR. Further efforts are needed to fully understand the reasons for significant divergences in reporting rates and to share lessons learned.

### Reporting mechanisms are fragmented

A range of different reporting mechanisms have been established across the various instruments in the international chemicals and waste cluster. Relying on this diverse set of parameters and indicators makes it challenging to develop a baseline and derive informed insights on the overall progress. Data from the various instruments are currently scattered in different Secretariats and databases, making it difficult to track overall progress in a systematic manner. The co-chairs' overview paper prepared for the second meeting of the intersessional process on the sound management of chemicals and waste beyond 2020, held in March 2018, stated that "countries have been burdened by their reporting obligations under different regimes" and noted that "reporting under the beyond 2020 structure should take this into account when determining reporting mechanisms" (SAICM Secretariat 2018). The low response rate for the third SAICM Progress Report emphasizes that such a reporting system is in need of a revision.

### Output-based indicators versus impact-based indicators

Most of the indicators currently used to monitor progress with the implementation of the different instruments are activity-, output- or instrument-based. These indicators do not provide information on the results achieved in protecting human health and the environment from the adverse effects of chemicals and waste. The activity-based indicators and related responses to questionnaires may also be subjective and open to a variety of responses. Consequently, it is often not possible to ascertain whether the health and environment related objectives of the agreements are actually achieved (Urho 2018). When using the results chain to assess progress, it can be concluded that a large number of activities and outputs are being/have been implemented. In the framework of SAICM, stakeholders have made progress by developing a set of 11 basic elements recognized as critical at the national and regional level to the attainment of sound chemicals and waste management, as outlined in the OOG for achieving the 2020 goal. However, these indicators do not provide conclusive insights regarding progress in minimizing the adverse impacts of chemicals and waste.

# Annex: Other issues where emerging evidence indicates a risk

## Arsenic

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | • Eurasian Economic Union (EEA) 2010, application of sanitary measures within the Customs Union | • Prohibits arsenic in milk dummies and pacifiers from silicone polymers and latex<br>• Limits arsenic in diapers and baby swaddling bands | • Potential health effects (risk to infants) |
| | • EU, EC 2015, Regulation (EC) No 2015/1006 amending Regulation (EC) No 2006/1881 on maximum levels for certain contaminants in foodstuffs | • Limits levels of arsenic in rice and restricts sale | • Potential health effects (risk to consumers, infants and young children) |
| | • Canada, 2016, Health Canada Expansion Gates and Expandable Enclosures Regulations, Cribs, Cradles and Bassinets Regulations and Toys Regulations, Canada Consumer Product Safety Act | • Limits the amount of arsenic in these sources | • Protection of human health with a special focus on children's health |
| | • Canada, 2016, Regulations under the Canada Food and Drugs Act for foods, drugs (2016) and natural health products | • Specifies maximum levels of arsenic in these products | • Protection of human health |
| | • Turkey 2017, Ministry of Environment and Urbanization (MoEU), KKDIK regulation (REACH-like regulation) | • Restricts the sale and use for use in anti-fouling, water treatment, wood preservation | • Potential effects on health and environment (risk to humans and animals) |
| Assessment actions and reports | US 2016, FDA Center for Food Safety and Applied Nutrition, Arsenic in Rice and Rice Products Risk Assessment Report | | |
| | EU 2017, ECHA, Committee for Risk Assessment (RAC) Opinion on Arsenic acid and its inorganic salts | | |
| Inclusion in existing prioritization initiatives | Global Environment Facility (GEF) Scientific and Technical Advisory Panel (STAP), *GEF Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition* (2012)<br>WHO's chemicals of major public health concern<br>Norway Environment Agency's List of Priority Substances (as of 2017) | | |

## Bisphenol A (BPA)

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | • Canada, 2010, Bisphenol A added to the Canada Consumer Products Safety Act, Schedule 2 | • Prohibits the import, sale and advertising of polycarbonate baby bottles containing BPA | • The concern is the health of newborns and infants under 18 months of age |
| | • China 2011, Ministry of Health Ban on the Use of BPA in Infant Food Containers | • Bans production of any BPA-containing baby bottles or other food and drink items for children | • Potential health effects (risk to people; children, infants and foetuses) |
| | • Malaysia 2011, Ministry of Health | • Bans production, import and sale of feeding bottles containing BPA | • Potential health effects (risk to people, children, infants and foetuses) |
| | • EU, EC 2011, Regulation (EC) 10/2011 amending Directive 2002/72/EC on plastic materials and articles intended to come into contact with food | • Limits the amount of BPA allowed to leach out of materials | • Potential health effects (risk to people, children, infants and foetuses) |
| | • EU, EC 2011, Regulation (EC) 321/2011 amending Regulation (EU) 10/2011 as regards the restriction of use of Bisphenol A in plastic infant feeding bottles | • Prohibits BPA in the manufacture of polycarbonate infant feeding bottles | • Potential health effects (risk to children and infants) |
| | • EU, EC 2016, Regulation (EC) 2016/2235, amending Annex XVII to Regulation (EC) No 1907/2006 (REACH Restriction List) | • Prohibits sale of thermal paper containing BPA | • Potential health effects (risk to workers, consumers, unborn children of pregnant workers) |
| | • EU, EC 2017, Directive (EU) 2017/898, amending Appendix C to Annex II to Directive 2009/48/EC on the safety of toys, as regards bisphenol A | • Lowers applicable specific limit value for BPA in toys | • Potential health effects (risk to children) |
| | • Turkey 2017, Ministry of Customs and Trade Amendment to the Safety of Toys Implementing Regulation Gazette number: 30025 | • Restricts the amount of BPA permissible for use in toys<br>• Mandates use of safety warning | • Potential health effects (risk to children less than 36 months old) |
| | • Canada 2017, Ministerial Condition No. 19233 of the Canadian Environmental Protection Act, 1999 | • Bans manufacture or import of consumer products with fatty acids, tall oil and reaction products containing BPA<br>• Regulates handling and disposal | • Potential effects on health, environment and biodiversity (risk to pregnant women, infants and foetuses) |
| | • EU, EC 2018, Regulation EC 2018/213, Bisphenol-A amendment to Regulation (EU) No 10/2011 on plastic and food contact material. To apply from September 2018 | • Restricts use of BPA in in varnishes and coatings | • Potential health effects (risk to consumers) |

| | Action | Scope | Concern |
|---|---|---|---|
| Assessment actions and reports | Canada, 2012 Health Canada's Updated Assessment of Bisphenol A (BPA) Exposure from Food Sources | | |
| | EU 2015, EFSA, Scientific Opinion on the risks to public health related to the presence of bisphenol A (BPA) in foodstuffs | | |
| | EU 2016, EFSA, A statement on the developmental immunotoxicity of bisphenol A (BPA): answer to the question from the Dutch Ministry of Health, Welfare and Sport | | |
| | Sweden 2017, Swedish Chemicals Agency (KEMI), Bisphenols – a survey and analysis | | |
| | EU 2017, Next EFSA Re-assessment on toxicity of bisphenol A (BPA) in 2018 | | |
| | US 2018, FDA National Toxicology Program (NTP), 2018, draft CLARITY-BPA Core Study Research Report | | |
| Inclusion in existing prioritization initiatives | Global Environment Facility (GEF) Scientific and Technical Advisory Panel (STAP), *GEF Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition* (2012)<br>Chemicals/groups of chemicals on which the US EPA issued a Chemical Action Plan (2011)<br>Norwegian Environment Agency's List of Priority Substances (as of 2017) | | |

## Glyphosate

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | France 2014, Loi n° 2014-110 du 6 février 2014 visant à mieux encadrer l'utilisation des produits phytosanitaires sur le territoire national | Forbids use of pesticides by the French state, local authorities and public bodies for the maintenance of public spaces, forests and roadsides | Potential health effects |
| | Netherlands 2016 | Bans sale of glyphosate to private parties | Potential health effects |
| | Italy 2016, Ministry of Health Restrictions on Glyphosate use | Prohibits use of glyphosate in public areas and pre-harvest use of glyphosate. Restricts non-agricultural use of glyphosate in soils | Potential effects on health and environment (risk to children and the elderly) |
| | Sri Lanka 2018 | Use of glyphosate banned except for tea and rubber cultivation | Potential health effects on farmers (kidney disease) |
| Assessment actions and reports | EU 2015, EFSA Peer review of the pesticide risk assessment of the EDC properties of glyphosate | | |
| | Canada 2017, Re-evaluation Decision RVD2017-01, Glyphosate. Catalogue number: H113-28/2017-1E-PDF | | |
| | US EPA 2017, Draft Human Health and Ecological Risk Assessments for Glyphosate. Review docket EPA-HQ-OPP-2009-0361 | | |
| Inclusion in existing prioritization initiatives | | | |

## Cadmium

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | • EU 2011, Directive 2011/65/EU, restriction of the use of certain hazardous substances (RoHS) in electrical and electronic equipment | • Restricts sale of electrical and electronic equipment (EEE) above certain cadmium levels | • Potential health effects (risk to consumers) |
| | • Canada 2016, Health Canada Surface Coating Materials Regulations, Glazed Ceramics and Glassware Regulations, Children's Jewellery Regulations, Expansion Gates and Expandable Enclosures Regulations, Cribs, Cradles and Bassinets Regulations and Toys Regulations, Canada Consumer Product Safety Act. | • Limits the amount of cadmium in these sources | • Protection of human health with a special focus on children's health |
| | • EU, EC 2016, Regulation (EC) 2016/217, amending Annex XVII to Regulation (EC) No 1907/2006 (REACH Restriction List) | • Restricts placing on the market of paints | • Potential effects on health and biodiversity (risk to humans and aquatic life) |
| | • EU, EC 2016, Circular economy package: rules on organic and waste-based fertilizers in the EU | • Restricts limits for cadmium in phosphate fertilizers | • Potential effects on health and environment (risk to humans and soils) |
| | • Republic of Korea 2016, Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles | • Restricts production and import<br>• Restricts levels of cadmium and its compounds in electrical products and vehicles | • Potential health effects (risk to consumers) |
| | • China 2017, Ministry of Environmental Protection (MEP), List of Priority Chemicals for Management (first batch), Notice No. 83 of 2017 | • Restricts production and use of cadmium<br>• Mandates disclosure of use or release of cadmium; mandates an application for a disposal permit | • Potential health effects and environment |
| | • UAE 2017, Emirates Authority for Standardization and Metrology RoHS regulation, Decision No. 10 of 2017 | • Restricts sale of electrical and electronic equipment (EEE) containing cadmium | • Potential health effects and environment (risk to consumers) |
| | • Eurasian Economic Union (EEU) 2018, alignment with EU (RoHS) | • Restricts sale of EEE containing cadmium | • Potential effects on health and environment (risk to humans and animals) |
| | • UK 2013, Food standards Agency, Final Report: A Survey of Cadmium in Brown Crabmeat and Brown Crabmeat Products | | |

| | Action | Scope | Concern |
|---|---|---|---|
| Assessment actions and reports | Norway 2015, Norwegian Scientific Committee for Food Safety (VKM), Risk assessment of dietary cadmium exposure. VKM 2015: 12 | | |
| | EU 2016, Impact assessment, limits for cadmium in phosphate fertilizers. An accompanying document to a proposal for an EC Regulation | | |
| | Global Environment Facility (GEF) Scientific and Technical Advisory Panel (STAP), *GEF Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition* (2012)<br>WHO's chemicals of major public health concern | | |
| Inclusion in existing prioritization initiatives | - | | |

## Lead

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | • The Philippines 2013, Department Administrative Order No. 2013- 24, Chemical Control Order for Lead and Lead Compounds | • Restricts import, manufacture, processing, sale, distribution, use and disposal<br>• Bans use in production of 7 types of consumer products | • Potential health effects (risk to children) |
| | • EU, EC 2015, Regulation (EU) 2015/628 amending Annex XVII to Regulation (EC) No 1907/2006 (REACH Restriction List) | • Expands scope of lead restriction from jewelry articles to articles or accessible parts of articles for the general public | • Potential health effects (risk to children) |
| | • Canada 2016, Health Canada Children's Jewellery Regulations, Canada Consumer Product Safety Act, SOR/2016-168 | • Limits lead content in children's jewelry | • Potential health effects (risk to children) |
| | • Canada 2016, Health Canada Surface Coating Materials Regulations, Glazed Ceramics and Glassware Regulations, Kettles Regulations, Cribs, Cradles and Bassinets Regulations and Toys Regulations, Canada Consumer Product Safety Act | • Limits the amount of lead in these sources. | • Protection of human health with a special focus on children's health |
| | • Canada, 2016, Regulations under the Canada Food and Drugs Act for foods, drugs and natural health products | • Specifies maximum levels of lead in these products | • Protection of human health |

| | Action | Scope | Concern |
|---|---|---|---|
| | • Singapore 2016, Ministry of the Environment and Water Resources, Environmental Protection and Management Act amendment | • Restricts manufacture, import and sale<br>• Restricts lead levels in certain electrical and electronic equipment (EEE) | • Potential health effects (risk to consumers) |
| | • United Arab Emirates (UAE) 2017, Emirates Authority for Standardization and Metrology RoHS regulation, Decision No. 10 of 2017. | • Restricts sale of electrical and electronic equipment (EEE) containing lead to a maximum concentration of 0.01 per cent | • Potential health effects (risk to consumers) |
| Assessment actions and reports | US 2012, US Department of Health and Human Services National Toxicology Program (NTP), NTP Monograph Health Effects of Low-level Lead Evaluation | | |
| | Canada 2013, Health Canada, Final Human Health State of the Science Report on Lead | | |
| | US 2013, EPA, Integrated Science Assessment for Lead | | |
| Inclusion in existing prioritization initiatives | Global Environment Facility (GEF) Scientific and Technical Advisory Panel (STAP), *GEF Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition* (2012)<br>World Health Organization (WHO) chemicals of major public health concern<br>Norwegian Environment Agency's List of Priority Substances (as of 2017) | | |

## Microbeads

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | • US 2015, Microbead-Free Waters Act (114-114) | • Prohibits manufacture, packaging and distribution of rinse-off cosmetics containing plastic microbeads | • Potential effects on the environment and biodiversity (risk to water supply, waterbodies and fish/ wildlife) |
| | • France 2017, Ministry of Environment, Energy and the Sea, Décret no 2017-291 | • Bans rinse-off cosmetic products for exfoliation or cleaning that contain solid plastic particles | • Potential effects on environment (marine environment, waterbodies and food chain) |
| | • Canada, 2017, Microbeads in Toiletries Regulations (SOR/2017-111) | • Prohibits manufacture, import and sale of toiletries used to exfoliate or cleanse that contain microbeads | • Potential effects on the environment and biodiversity (risk to freshwater, marine ecosystems and non-human species) |
| | • Taiwan 2017, EPA Waste Management Division, Administrative order | • Bans manufacture, import, use and sale of microbeads | • Potential effects on the environment |
| | • New Zealand 2017, Ministry of Environment, Plastic microbeads ban, 2017/291 amending the 2008 Waste Minimization Act | • Bans sale and manufacture of wash-off products containing plastic microbeads | • Potential effects on the environment (risk of non-biodegradable microbeads) |

| | Action | Scope | Concern |
|---|---|---|---|
| | • UK 2017, Department for Environment, Food & Rural Affairs, The Environmental Protection (Microbeads) (England) Regulations, 2017 No. 1312) | • Bans manufacture and sale of cosmetics and rinse-off personal care products with plastic microbeads | • Potential effects on biodiversity (risk to marine life) |
| | • Sweden 2018, Ministry of the Environment and Energy | • Bans sale of cosmetics and rinse-off personal care products with plastic microbeads | • Potential effects on biodiversity (risk to marine life) |
| | • UK: Northern Ireland 2018, Department of Agriculture, Environment and Rural Affairs | • Prohibits use of microbeads as an ingredient in manufacture of rinse-off personal care products and sale of any such products containing microbeads | • Potential harm to living species in the marine environment |
| | • UK: Scotland 2018, Marine Scotland | • Prohibits use of microbeads as an ingredient in manufacture of rinse-off personal care products and sale of any such products containing microbeads | • Potential harm to living species in the marine environment |
| | • UK: Wales 2018, Marine and Fisheries Division | • Prohibits use of microbeads as an ingredient in manufacture of rinse-off personal care products and sale of any such products containing microbeads | • Potential harm to living species in the marine environment |
| Assessment actions and reports | Canada, 2015, Microbeads – A Science Summary | | |
| | UK 2016, the government is to conduct an investigation into the impact on human health of microplastic particles found in shellfish and other marine animals | | |
| | Denmark 2017, Danish Environmental Protection Agency, Partnership on Microplastics in wastewater 2017 | | |
| | Sweden 2018, Swedish Chemicals Agency (KEMI), Microplastic in cosmetic products and other chemical products Report 2/18 | | |
| Inclusion in existing prioritization initiatives | Included in AMAP's Chemicals of Emerging Arctic Concern (2017) | | |

## Neonicotinoids

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | • EU, EC 2013, Regulation 485/2013, amending Regulation (EU) No 540/2011 (clothianidin, thiamethoxam and imidacloprid) | • Prohibits use in bee-attractive crops | • Potential effects on biodiversity (risk to bees) |
| Assessment actions and reports | EU, EC 2012, EFSA pesticide risk assessment for bees for three neonicotinoids | | |
| | EU, EC 2011, ECHA Assessment report of Imidacloprid in insecticides | | |
| | Canada, 2012, Health Canada, Pest Management Regulatory Agency, Re-evaluation of Neonicotinoid Insecticides | | |
| | EU, EC 2012, ECHA Assessment report of Thiamethoxam in wood preservatives and insecticides | | |
| | EU, EC 2014, ECHA Assessment reports of Clothianidin in wood preservatives and insecticides | | |
| | EU, EC 2014, ECHA Assessment report of Dinotefuran in wood preservatives | | |
| | US EPA 2016, ongoing review and risk assessment to be completed in 2018/2019 (pollinator-only assessment for clothianidin, thiamethoxam, dinotefuran; updated preliminary risk assessment for imidacloprid) | | |
| | Canada, 2016, Health Canada, Pest Management Regulatory Agency (PMRA), Proposed Re-evaluation Decision PRVD2016-20, Imidacloprid | | |
| | Canada, 2017, Health Canada, Pest Management Regulatory Agency (PMRA), Update on the Neonicotinoid Pesticides | | |
| | Canada, 2017, Health Canada, Pest Management Regulatory Agency (PMRA), Proposed Re-evaluation Decision PRVD2017-23, Clothianidin and Its Associated End-use Products: Pollinator Re-evaluation | | |
| | Canada, 2017, Health Canada, Pest Management Regulatory Agency (PMRA), Proposed Re-evaluation Decision PRVD2017-24, Thiamethoxam and Its Associated End-use Products: Pollinator Re-evaluation | | |
| | Canada, 2018, Health Canada, Pest Management Regulatory Agency (PMRA), Proposed Re-evaluation Decision PRVD2018-12, Imidacloprid and Its Associated End-use Products: Pollinator Re-evaluation | | |
| | Canada, 2018, Health Canada, Pest Management Regulatory Agency (PMRA), Proposed Special Review Decision PSRD2018-01, Clothianidin: Special Review of Risk to Aquatic Invertebrates | | |
| | Canada, 2018, Health Canada, Pest Management Regulatory Agency (PMRA), Proposed Special Review Decision PSRD2018-02, Thiamethoxam: Special Review of Risk to Aquatic Invertebrates. | | |
| | EU 2018, EFSA, Evaluation of the data on clothianidin, imidacloprid and thiamethoxam for the updated risk assessment to bees for seed treatments and granules in the EU | | |
| Inclusion in existing prioritization initiatives | - | | |

## Organotins

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | Canada, 2012 Prohibition of Certain Toxic Substances Regulations (Tributyltins , which contain the grouping (C4H9)3Sn added in 2013) | Prohibits the manufacture, use, sale, offer for sale or import of the substance, and products containing it | Potential effects on the environment or its biological diversity |
| | EU, EC 2014, Regulation 1257/2013 on ship recycling and amending Regulation (EC) No 1013/2006 and Directive 2009/16/EC | Restricts use of anti-fouling systems containing organotin compounds as a biocide | Potential effects on health and marine environment |
| | China 2015, Merchant Shipping (Control of Harmful Anti-Fouling Systems on Ships) Regulation, L.N. 54 of 2015 | Bans organotin compounds acting as biocides in anti-fouling systems of ships | Potential effects on health and marine environment |
| | Thailand 2017, Department of Labour Protection and Welfare of Thailand, notification on concentration limits of dangerous chemicals. Gazette: Book 134 Special Episode 198 | Limits concentration of cyhexatin (tricyclohexyltin hydroxide) in the workplace and in hazardous chemical storage facilities | Potential health effects (risk to workers) |
| | Canada, 2018 Guideline for the environmental management of tin stabilizers in Canada in 2018 | This guideline addresses in-plant handling methods for tin stabilizers and also the management of tin stabilizer packaging. | Harmful effects to aquatic organisms if allowed to enter the aquatic environment |
| Assessment actions and reports | Canada 2010, Health Canada, Pest Management Regulatory Agency (PMRA), Re-evaluation Decision - Tributyltin Compounds (RVD1017-01); | | |
| | Canada 2010, Health Canada, Pest Management Regulatory Agency (PMRA), Proposed Re-evaluation Decision, Tributyltin Compounds (PRVD2010-11); Canada 2002, Health Canada, Pest Management Regulatory Agency (PMRA), Special Review Decision, Tributyltin Antifouling Paints for Ship Hulls (SRD2002-01) | | |
| | Denmark 2013, Danish Tributyltin compounds (TBT) assessment, Environmental Project No. 1524, 2013 | | |
| Inclusion in existing prioritization initiatives | Global Environment Facility (GEF) Scientific and Technical Advisory Panel (STAP), *GEF Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition* (2012) | | |

## Polycyclic aromatic hydrocarbons (PAHs)

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | EU, EC 2014, Regulation 1272/2013, amending Annex XVII to Regulation (EC) No 1907/2006 REACH Restriction List (8PAHs) | Restriction extended to rubber and plastic components of article with direct and prolonged or short-term repetitive contact with skin or mouth | Potential health effects (risk to consumers and children) |

| | Action | Scope | Concern |
|---|---|---|---|
| | Germany 2014, Product Safety Commission, "Testing and Assessment of PAHs" (18 PAHs) | Restricts PAH content in articles and consumer products | Potential health effects (risk to consumers) |
| | EU, EC 2015, Regulation 2015/1933, amending Annex XVII to Regulation (EC) No 1907/2006 (REACH Restriction List) | Restricts sale and sets maximum levels PAHs in certain foodstuffs | Potential health effects |
| | Turkey 2017 Ministry of Environment and Urbanization (MoEU), KKDIK regulation (REACH-like regulation) Annex 17 (8 PAHs) | Restricts PAH content in articles and consumer products | Potential health effects (risk to consumers and children) |
| Assessment actions and reports | Denmark 2013, Danish EPA, Polyaromatic Hydrocarbons (PAH) Evaluation of health hazards and estimation of a quality criterion in soil, Environmental Project No. 1523, 2013 | | |
| Inclusion in existing prioritization initiatives | Global Environment Facility (GEF) Scientific and Technical Advisory Panel (STAP), *GEF Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition* (2012)<br>Norwegian Environment Agency's List of Priority Substances (as of 2017)<br>Arctic Monitoring and Assessment Programme (AMAP) Chemicals of Emerging Arctic Concern (2017) | | |

## Phthalates

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | • Republic of Korea 2014, Ministry of Food and Drug Safety, Regulations on medical device approval, notification and examination (3 phthalates: DBP, BBP and DEHP) | • Prohibits the production, import sale or use of intravascular administration medical devices containing phthalates | • Potential health effects (risk to lactating women, pregnant women, newborn babies, infants, children and the elderly) |
| | • EU, EC 2015, Directive (EU) 2015/863, amending Annex II to Directive 2011/65/EU (4 phthalates: DEHP, BBP, DBP, DIBP) | • Restricts use in all electrical and electronic equipment (apart from medical devices and monitoring and control equipment) | • Potential health effects (risk to workers) |
| | • China 2015, General Administration of Quality Supervision, Inspection and Quarantine and the Standardization Administration, New Safety Technical Code for Infants and Children Textile Products (6 phthalates: DEHP, DBP, BBP, DINP, DNOP, DIDP) | • Restricts use in infants' and children's textile products | • Potential health effects (risk to infants and children) |
| | • China 2016, National Food Safety Standard GB9685-2016 (4 phthalates: DMP, DIBP, DIOP, DIDP) | • Prohibits use as additives in food contact materials | • Potential health effects (risk to consumers) |

| | Action | Scope | Concern |
|---|---|---|---|
| | • Canada, 2016, Canada Consumer Product Safety Act, Phthalates Regulations (6 phthalates: DEHP, DBP, BBP, DINP, DIDP, DNOP) | • Restricts concentrations of DEHP, DBP, and BBP to 1 000 mg/kg in the vinyl of a toy or child care article<br>• Restricts concentrations of DINP, DIDP, and DNOP to 1 000 mg/kg in the vinyl in any part of a toy or child care article that can be reasonably be mouthed by a child under four years of age | • Potential health effects |
| | • United States (US) 2017, Consumer Product Safety Commission (CPSC), Prohibition of Children's Toys and Child Care Articles Containing Specified Phthalates under section 108 of the Consumer Product Safety Improvement Act of (2008) (5 phthalates: DIBP, DPENP, DHEXP, DCHP, DINP) | • Prohibits children's toys and child care articles containing more than 0.1 per cent of certain phthalate chemicals | • Potential health effects (risk to males, infants and children) |
| Assessment actions and reports | US 2012, EPA, Phthalates Action Plan | | |
| | EU 2013, European Chemicals Agency (ECHA), Evaluation of new scientific evidence concerning DINP and DIDP in relation to entry 52 of Annex XVII to REACH Regulation (EC) No 1907/2006 | | |
| | India 2016, Ministry of Health and Family Welfare, Report of the Committee to assess the health and environmental impact of the use of Polyethylene Terephthalate (PET) or Plastic containers for primary packaging of drug formulations | | |
| | Canada 2017, Draft Screening Assessment for the Phthalate Substance Grouping | | |
| | EU 2018, ECHA, Committee for Risk Assessment Opinion proposing harmonized classification and labelling at EU level of DINP | | |
| Inclusion in existing prioritization initiatives | Global Environment Facility (GEF) Scientific and Technical Advisory Panel (STAP), GEF Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition (2012)<br>Chemicals/groups of chemicals for which the US EPA issued a Chemical Action Plan (2011)<br>Norwegian Environment Agency's List of Priority Substances (as of 2017)<br>Arctic Monitoring and Assessment Programme (AMAP) Chemicals of Emerging Arctic Concern (2017) | | |

## Triclosan

| | Action | Scope | Concern |
|---|---|---|---|
| Regulatory actions | • EU, EC 2014, Regulation (EU) No 358/2014 of 9 April 2014 amending Annexes II and V to Regulation (EC) No 1223/2009 of the European Parliament and of the Council on cosmetic products | • Restricts maximum concentration of triclosan in certain cosmetic products | • Potential health effects |
| | • US 2016, Food and Drug Administration (FDA) final rule on safety and effectiveness of antibacterial soaps | • Restricts placing on market of over-the-counter (OTC) consumer rinse-off antiseptic wash products containing triclosan and 18 other active ingredients | • Potential health effects |
| | • EU, EC 2016, Implementing Decision (EU) 2016/110 of 27 January 2016 not approving triclosan as an existing active substance for use in biocidal products for product-type 1 | • Restricts use of triclosan as an active substance in human hygiene biocidal products | • Potential effects on the environment (unacceptable risks for surface water and secondary poisoning of non-target species) |
| | • Canada, 2018, Triclosan was added to the List of Toxic Substances of the Canadian Environmental Protection Act, 1999. | • An instrument is currently under development to manage the risk triclosan poses to the environment | • Potential effects on the environment and biodiversity |
| Assessment actions and reports | Canada, 2016, Environment and Climate Change Canada Health Canada, Assessment of Triclosan - found that it is toxic to the environment above certain levels, but is not toxic to humans at current levels of exposure | | |
| | EU 2015, ECHA. Opinion on the application for approval of the active substance: Triclosan Product-type: 1 | | |
| Inclusion in existing prioritization initiatives | Norwegian Environment Agency's List of Priority Substances (as of 2017) | | |

# References


## Chapter 1

Food and Agriculture Organization of the United Nations (2018). AGP - International Code of Conduct on Pesticide Management. http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/en/. Accessed 31 January 2019.

International Labour Organization (2017a). Convention C170: Chemicals Convention, 1990. https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C170. Accessed 31 January 2019.

International Labour Organization (2017b). Convention C174: Prevention of Major Industrial Accidents Convention, 1993. https://www.ilo.org/dyn/normlex/en/f?p=1000:12100:::NO:12100:P12100_INSTRUMENT_ID:312319. Accessed 31 January 2019.

Organisation for the Prohibition of Chemical Weapons (2019). Chemical Weapons Convention. https://www.opcw.org/chemical-weapons-convention/. Accessed 31 January 2019.

Persson, L., Persson, Å. and Sam, C. (2014). *The Strategic Approach to International Chemicals Management in Cambodia: Barriers and Opportunities*. Stockholm: Stockholm Environment Institute. https://www.sei.org/mediamanager/documents/Publications/SEI-PolicyBrief-Persson-Chemicals-Cambodia.pdf.

Secretariat of the Basel Convention (2011a). New strategic framework. http://www.basel.int/TheConvention/StrategicPlan/NewStrategicFramework/tabid/1546/Default.aspx. Accessed 8 November 2018.

Secretariat of the Basel Convention (2011b). Convention overview. http://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx. Accessed 27 August 2018.

Secretariat of the Rotterdam Convention (2010). Rotterdam Convention text: Rotterdam Convention on the Prior informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade. http://www.pic.int/TheConvention/Overview/TextoftheConvention/RotterdamConventionText/tabid/1160/language/en-US/Default.aspx. Accessed 27 August 2018.

Secretariat of the Stockholm Convention (2008). Convention text. http://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx. Accessed 27 August 2018.

Secretariat of the Strategic Approach to International Chemicals Management, United Nations Environment Programme and World Health Organization (2006). *Strategic Approach to International Chemicals Management: SAICM Texts and Resolutions of the International Conference on Chemicals Management.* http://www.saicm.org/Portals/12/Documents/saicmtexts/New%20SAICM%20Text%20with%20ICCM%20resolutions_E.pdf.

United Nations (2018). Montreal Protocol on Substances that Deplete the Ozone Layer.

United Nations Environment Programme (2018). Minamata Convention on Mercury. http://www.mercuryconvention.org/Home/tabid/3360/language/en-US/Default.aspx. Accessed 5 September 2018.

World Health Organization (2016). *International Health Regulations (2005).* 3rd edn. http://www.who.int/ihr/publications/9789241580496/en/.

## Chapter 2

Food and Agriculture Organization of the United Nations and World Health Organization (2014*). The International Code of Conduct on Pesticide Management.* http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/CODE_2014Sep_ENG.pdf.

Honkonen, T. and Khan, S.A. (2017). *Chemicals and Waste Governance beyond 2020: Exploring Pathways for a Coherent Global Regime*. Copenhagen: Nordic Council of Ministers. http://dx.doi.org/10.6027/TN2017-502.

Inter-agency and Expert Group on Sustainable Development Goal Indicators (2018). *Tier Classification for Global SDG Indicators.* https://unstats.un.org/sdgs/files/Tier Classification of SDG Indicators_11 May 2018_web.pdf.

International Labour Organization (n.d. a). Committee of experts on the application of conventions and recommendations. https://www.ilo.org/global/standards/applying-and-promoting-international-labour-standards/committee-of-experts-on-the-application-of-conventions-and-recommendations/lang--en/index.htm. Accessed 27 August 2018.

International Labour Organization (n.d. b). Conference committee on the application of standards. https://www.ilo.org/global/standards/applying-and-promoting-international-labour-standards/conference-committee-on-the-application-of-standards/lang--en/index.htm. Accessed 27 August 2018.

Inter-Organization Programme for the Sound Management of Chemicals (2010). IOMC indicators of progress in implementing SAICM. http://www.who.int/iomc/indicators_saicm/en/. Accessed 1 February 2019.

Organisation for Economic Cooperation and Development (2018). *Decision-Recommendation of the Council on the Cooperative Investigation and Risk Reduction of Chemicals. OECD/LEGAL/0441.* https://legalinstruments.oecd.org/public/doc/638/638.en.pdf.

Secretariat of the Basel Convention (2011). National reporting: overview and mandate. http://basel.int/Countries/NationalReporting/OverviewandMandate/tabid/2314/Default.aspx. Accessed 27 August 2018.

Secretariat of the Basel, Rotterdam and Stockholm Conventions (2018). Synergies among the Basel, Rotterdam and Stockholm Conventions. http://www.brsmeas.org/. Accessed 5 June 2018.

Secretariat of the Minamata Convention on Mercury (2017). *Timing and Format of the Reporting to be Followed by the Parties, as set out in Paragraph 3 of Article 21.* http://www.mercuryconvention.org/Portals/11/documents/meetings/COP1/English/1_11_e_reporting.pdf.

Secretariat of the Multilateral Fund for the Implementation of the Montreal Protocol (2018) *Executive Committee Primer – 2018.* http://www.multilateralfund.org/aboutMLF/executivecommittee/Shared%20Documents/2018Primer.pdf.

Secretariat of the Stockholm Convention (2018). Reporting: national reports. http://chm.pops.int/Countries/Reporting/NationalReports/tabid/3668/Default.aspx. Accessed 27 August 2018.

Secretariat of the Strategic Approach to International Chemicals Management (2009). *Proposal on Modalities for Reporting by Stakeholders on Progress in Implementation Proposal on Modalities for Reporting by Stakeholders on Progress in Implementation*. http://www.saicm.org/Portals/12/documents/meetings/ICCM2/doc/ICCM2 3 reporting E.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2011). *Draft Baseline Estimates Report (2006-2008): Progress in Implementation of the Strategic Approach to International Chemicals Management Progress*. http://www.saicm.org/Portals/12/documents/meetings/OEWG1/inf/OEWG1 INF1_Baseline report.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2012). *Progress in Implementation of the Strategic Approach to International Chemicals Management for 2009 and 2010*. http://www.saicm.org/Portals/12/documents/meetings/ICCM3/inf/ICCM_3_INF6_first progress report_Final.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2014a). *Progress in Strategic Approach Implementation for 2011-2013*. http://www.saicm.org/Portals/12/documents/meetings/OEWG2/inf/k1403579-eowg2-inf4.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2014b). *Overall Orientation and Guidance for Achieving the 2020 Goal of Sound Management of Chemicals*. http://www.saicm.org/Portals/12/documents/meetings/OEWG2/doc/k1402879 saicm-eowg2-4-e.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2017). *Thought Starter for the First Meeting of the Intersessional Process*. http://www.saicm.org/Portals/12/documents/meetings/IP1/IP_1_4_Thought_Starter.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2018a). International Conference on Chemicals Management. http://www.saicm.org/About/ICCM/tabid/5521/Default.aspx. Accessed 11 September 2018.

Secretariat of the Strategic Approach to International Chemicals Management (2018b). *Proposal on Objectives in Support of the 2030 Agenda and Related Milestones*. http://www.saicm.org/Portals/12/Documents/meetings/IP2/IP_2_8_OBJECTIVES AND SDG.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2019). *Progress in Strategic Approach Implementation for 2014 - 2016*. http://www.saicm.org/Portals/12/Documents/meetings/OEWG3/inf/OEWG3-INF-4-2014-16-third-Progress-Report-.pdf.

Stringer, L. (2018). OECD makes GHS mandatory for member states, 19 July. *Chemical Watch*. https://chemicalwatch.com/68828/oecd-makes-ghs-mandatory-for-member-states. Accessed 1 February 2019.

United Nations (2016). *Final List of Proposed Sustainable Development Goal Indicators*. https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf.

United Nations (2018) Sustainable development knowledge platform. https://sustainabledevelopment.un.org/. Accessed 11 September 2018.

United Nations Economic Commission for Europe (n.d.). GHS implementation. https://www.unece.org/trans/danger/publi/ghs/implementation_e.html. Accessed 1 January 2019.

United Nations Statistics Division (2018). Methodology: standard country or area codes for statistical use (M49). https://unstats.un.org/unsd/methodology/m49/. Accessed 27 August 2018.

Urho, N. (2018). *Options for Effective Governance of the Beyond-2020 Framework for Sound Management of Chemicals and Waste: Lessons Learned from Other Regimes*. Boston, MA: Center for Governance and Sustainability, University of Massachusetts Boston. http://environmentalgovernance.org/wp-content/uploads/2018/07/DOWNLOAD-THE-REPORT.pdf.

World Health Organization (2017). *Chemicals Road Map: Road Map to Enhance Health Sector Engagement in the Strategic Approach to International Chemicals Management Towards the 2020 Goal and Beyond*. http://www.who.int/ipcs/saicm/roadmap/en/.

World Health Organization (2018a). IHR core capacities implementation status: chemical. http://www.who.int/gho/ihr/monitoring/chemical/en/index1.html. Accessed 27 August 2018.

World Health Organization (2018b). Strengthening health security by implementing the International Health Regulations (2005): IHR (2005) monitoring and evaluation framework. http://www.who.int/ihr/publications/WHO_HSE_GCR_2016_2/en/. Accessed 11 September 2018.

## Chapter 3

Agarwal, M. and Garg, S. (2015). *Study on Sub-Standard, Spurious/Counterfeit Pesticides in India*. New Delhi: Federation of Indian Chambers of Commerce and Industry. http://ficci.in/spdocument/20641/Pestiside-Report.pdf.

Agerstrand, M., Sobek, A., Lilja, K., Ruden, C. (2017). An academic researcher's guide to increased impact on regulatory assessment of chemicals. *Environmental Science: Processes and Impacts* 19(5), 644-655. https://doi.org/10.1039/C7EM00075H.

Association of Southeast Asian Nations (n.d.). ASEAN cooperation on chemicals and waste. https://environment.asean.org/awgcw/. Accessed 11 September 2018.

Bengtsson, G. (2010). Global trends in chemicals management. In *Regulating Chemical Risks*. Eriksson, J., Gilek, M., and Rudén, C. (eds). Dordrecht: Springer. Chapter 12. 179-215. https://doi.org/10.1007/978-90-481-9428-5_12.

Bernhardt, E.S., Rosi, E.J. and Gessner, M.O. (2017). Synthetic chemicals as agents of global change. *Frontiers in Ecology and the Environment* 15(2), 84-90. https://doi.org/10.1002/fee.1450.

Brown-Weiss, E. and Jacobson, H.K. (eds) (1998). *Engaging Countries: Strengthening Compliance with International Environmental Accords*. Cambridge, MA: MIT Press. https://mitpress.mit.edu/books/engaging-countries

Buonsante, V.A., Muilerman, H., Santos, T., Robinson, C. and Tweedale, A.C. (2014). Risk assessment□s insensitive toxicity testing may cause it to fail. *Environmental Research* 135, 139-147. https://doi.org/10.1016/j.envres.2014.07.016.

Center for International Environmental Law (2015). Provisions of the Montreal Protocol affecting trade. https://www.ciel.org/reports/provisions-of-the-montreal-protocol-affecting-trade/. Accessed 11 September 2018.

Chemical Inspection and Regulation Service (2018). China MEP published list of priority chemicals, 5 January. http://www.cirs-reach.com/news-and-articles/China-MEP-Published-List-of-Priority-Chemicals.html. Accessed 25 May 2018.

Chemical Inspection and Regulation Service (2019). Revised K-REACH - The Act on the Registration and Evaluation of Chemicals, 23 January. http://www.cirs-reach.com/news-and-articles/revised-korea-reach---the-act-on-the-registration-and-evaluation-of-chemicals.html. Accessed 4 February 2019.

Chemical Watch (2013a). China publishes list of 58 substances for control measures, 27 February. https://chemicalwatch.com/13952/china-publishes-list-of-58-substances-for-control-measures. Accessed 28 August 2018.

Chemical Watch (2013b). Thailand to streamline hazardous chemical law, 30 May. https://chemicalwatch.com/15029/thailand-to-streamline-hazardous-chemical-law. Accessed 28 August 2018.

Chemical Watch (2013c). Gulf states advance revised toy safety standards, 18 June. https://chemicalwatch.com/15328/gulf-states-advance-revised-toy-safety-standards. Accessed 28 August 2018.

Chemical Watch (2017a). Turkey publishes law modelled on REACH, 29 June. https://chemicalwatch.com/57284/turkey-publishes-law-modelled-on-reach. Accessed 28 August 2018.

Chemical Watch (2017b). Gulf states notify WTO of cosmetics regulations, 27 April. https://chemicalwatch.com/55492/gulf-states-notify-wto-of-cosmetics-regulations. Accessed 28 August 2018.

Chemical Watch (2017c). Arab states notify WTO of draft detergent regulation, 19 December. https://chemicalwatch.com/62693/arab-states-notify-wto-of-draft-detergent-regulation. Accessed 28 August 2018.

Chemical Watch (2018a). China's MEP publishes first batch of priority control chemicals, 11 January. https://chemicalwatch.com/63032/chinas-mep-publishes-first-batch-of-priority-control-chemicals. Accessed 28 August 2018.

Chemical Watch (2018b). Serbia takes step towards EU chemical, biocidal law alignment, 19 March. https://chemicalwatch.com/64971/serbia-takes-step-towards-eu-chemical-biocidal-law-alignment. Accessed 28 August 2018.

Chemical Watch (2018c). Ukraine implements RoHS-like regulation, 9 January. https://chemicalwatch.com/62952/ukraine-implements-rohs-like-regulation. Accessed 28 August 2018.

Chemical Watch (2018d). Mercury found in fake UK cosmetics product, 29 August. https://chemicalwatch.com/69967/mercury-found-in-fake-uk-cosmetics-product. Accessed 11 September 2018.

ChemSafetyPro (2015). China IECSC: inventory of existing chemical substances in China, 30 December. http://www.chemsafetypro.com/Topics/China/China_IECSC_Inventory_Existing_Substances.html. Accessed 25 May 2018.

ChemSafetyPro (2016a). Thailand hazardous substance act, 1 May. https://www.chemsafetypro.com/Topics/Thailand/Thailand_Hazardous_Substance_Act.html. Accessed 28 August 2018.

ChemSafetyPro (2016b). Russia national existing chemical substance inventory, 12 August. https://www.chemsafetypro.com/Topics/Russia/Russia_National_Existing_Chemical_Substance_Inventory.html. Accessed 28 August 2018.

ChemSafetyPro (2017). Vietnam chemicals decree No. 113/2017/ND-CP. https://www.chemsafetypro.com/Topics/Vietnam/Vietnam_chemicals_decree_No_113_2017_ND_CP.html. Accessed 30 March 2019.

Chile Ministry of the Environment (2017). *National Policy on Chemical Safety 2017-2022 Action Plan*. Government of Chile. http://portal.mma.gob.cl/wp-content/uploads/2017/11/seguridad-quimica.pdf.

Colombia National Council of Economic and Social Policy (2016). *Risk Management Policy Associated with the Use of Chemical Substances*. Government of Colombia. https://colaboracion.dnp.gov.co/CDT/Conpes/Económicos/3868.pdf.

Comunidad Andina (n.d.). Portal de la comunidad andina. http://www.comunidadandina.org/index.aspx. Accessed 11 September 2018.

Costa Rica Directorate of Environmental Quality Management (2017). *Executive Decree No. 40148: Declaration of Public Interest and promulgation of The National Chemical Safety Policy*. San José: Government of Costa Rica. http://www.digeca.go.cr/sites/default/files/decreto_ejecutivo_no_40148_politica_de_seguridad_quimica.pdf.

CropLife International (2018a). *Ensuring the Sound Management of Pesticides*. Stockholm: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_11_Croplife_PesticideManagement_f.pdf.

CropLife International (2018b) Anti-counterfeiting. https://croplife.org/crop-protection/anti-counterfeiting/. Accessed 21 November 2018.

Ecuador Ministry of Environment (2003). *Unified Text on Subsidiary Legislation of the Ministry of the Environment Part 1: Executive Decree No. 31589*. Government of Ecuador. http://www.ambiente.gob.ec/wp-content/uploads/downloads/2015/06/Texto-Unificado-de-Legislacion-Secundaria-del-Ministerio-del-Ambiente.pdf.

Egeghy, P.P., Judson, R., Gangwal, S., Mosher, S., Smith, D., Vail, J. and Cohen Hubal, E.A. (2012). The exposure data landscape for manufactured chemicals. *Science of The Total Environment* 414, 159-166. https://doi.org/10.1016/j.scitotenv.2011.10.046.

Environment and Social Development Organization (2013). *Study Report on "Toxic Toys" Heavy Metal Content & Public Perception in Bangladesh*. https://ipen.org/sites/default/files/documents/ESDO%20Study%20Report%20on%20Toxic%20Toys%20in%20Bangladesh.pdf.

European Chemicals Agency (2016). *Report on the Operation of REACH and CLP 2016*. https://echa.europa.eu/documents/10162/13634/operation_reach_clp_2016_en.pdf.

European Chemicals Agency (2017). *REACH: The Story So Far and the Next Ten Years*. https://www.hsa.ie/eng/Chemicals/REACH/Session-1.pdf.

European Chemicals Agency (2018). *Community Rolling Action Plan Update Covering Years 2018, 2019 and 2020*. https://echa.europa.eu/documents/10162/9801478/corap_update_2018-2020_en.pdf/85e5f709-da61-8b06-855c-79302dc17c70.

European Chemicals Agency (n.d. a) SVHC roadmap to 2020 implementation. https://echa.europa.eu/svhc-roadmap-to-2020-implementation. Accessed 11 November 2018.

European Chemicals Agency (n.d. b). REACH registration results - ECHA. https://echa.europa.eu/de/reach-registrations-since-2008. Accessed 9 July 2018.

European Chemicals Agency (n.d. c). Candidate list of substances of very high concern for authorisation. https://echa.europa.eu/en/candidate-list-table. Accessed 15 May 2018.

European Commission (2018). Notification detail: The ministerial decree no. 1307/2017 (2 pages, in Arabic) mandating the Egyptian standards. http://ec.europa.eu/growth/tools-databases/tbt/en/search/?tbtaction=search.detail&Country_id=EGY&num=183&dspLang=EN&basdatedeb=&basdatefin=&baspays=HUN&basnotifnum=30&basnotifnum2=&bastypepays=&baskeywords=&CFID=714140&CFTOKEN=3fce0e481a854b67-4E5. Accessed 28 August 2018.

European Union Intellectual Property Office (2017). *The Economic Cost of IPR Infringement in the Pesticides Sector: Quantification of Infringement in Manufacture of Pesticides and Other Agrochemical Products (NACE 20.20)*. https://euipo.europa.eu/tunnel-web/secure/webdav/guest/document_library/observatory/resources/research-and-studies/ip_infringement/study10/pesticides_sector_en.pdf.

Europol (2018). Largest-ever seizure of illegal or counterfeit pesticides in Europol Silver Axe operation, 11 July. https://www.europol.europa.eu/newsroom/news/largest-ever-seizure-of-illegal-or-counterfeit-pesticides-in-europol-silver-axe-operation. Accessed 19 February 2019.

Food and Agriculture Organization of the United Nations (2018). AGP – International Code of Conduct on Pesticide Management: world map on pesticide legislation, February. http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/en/. Accessed 31 January 2019.

Food and Agriculture Organization of the United Nations (2019). FAOLEX database. http://www.fao.org/faolex/en/. Accessed 4 February 2019.

Food and Agriculture Organization of the United Nations and World Health Organization (2014). *The International Code of Conduct on Pesticide Management*. http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/CODE_2014Sep_ENG.pdf.

Garlapati, V.K. (2016). E-waste in india and developed countries: management, recycling, business and biotechnological initiatives. *Renewable and Sustainable Energy Reviews* 54, 874-881. https://doi.org/10.1016/j.rser.2015.10.106.

German Association for International Cooperation (2014). *Chemical Safety GIZ Convention Project: Managing Chemicals Properly. The Role of Chemicals in Modern Life*. https://www.global-chemicals-waste-platform.net/fileadmin/files/doc/A5-webformat.pdf.

Global Business Briefing (2017). India to have a national action plan for chemicals by 2018, November. https://chemicalwatch.com/60306/india-to-have-a-national-action-plan-for-chemicals-by-2018. Accessed 28 August 2018.

Global Environment Facility (2014). *Report on the Sixth Replenishment of the GEF Trust Fund*. https://www.thegef.org/sites/default/files/council-meeting-documents/GEF.A.5.07.Rev_.01_Report_on_the_Sixth_Replenishment_of_the_GEF_Trust_Fund_May_22_2014_1.pdf.

Global Environment Facility (2018). Projects. https://www.thegef.org/projects. Accessed 20 November 2018.

Government of Canada (2017) Canada-United States Regulatory Cooperation Council Initiative on Chemicals Management, 6 October. https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan/canada-united-states-regulatory-cooperation-council.html. Accessed 12 December 2018.

Government of Canada (2018a). Domestic substances list, 7 June. https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/substances-list/domestic.html. Accessed 4 February 2019.

Government of Canada (2018b). *Chemicals Management Plan, Progress Report: Summer 2018* https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/chemicals-management-plan-progress-report/summer-2018.html.

Government of Canada (2018c). *Follow-up Report to the Standing Committee on the Canadian Environmental Protection Act*. https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/review/standing-committee-report-cepa-2018.html.

Grandjean, P., Eriksen, M.L., Ellegaard, O. and Wallin, J.A. (2011). The Matthew effect in environmental science publication: a bibliometric analysis of chemical substances in journal articles. *Environmental Health* 10(1), 96. https://doi.org/10.1186/1476-069X-10-96.

Guatemala Ministry of Environment and Natural Resources (2013). *Government Agreement No. 341-2013: National Policy for Management Environmentally Rational Chemical Products and Waste Dangerous in Guatemala*. Government of Guatemala. http://www.sia.marn.gob.gt/publicaciones/Politicas%20Marn/12%20Pol%C3%ADtica%20Nacional%20de%20Productos%20Qu%C3%ADmicos.pdf.

Hazlewood, N. (2018). Arab states notify WTO of RoHS-like regulation, 04 April. *Chemical Watch*. https://chemicalwatch.com/65677/arab-states-notify-wto-of-rohs-like-regulation. Accessed 28 August 2018.

Hazlewood, N. (2019). Kenya moves towards implementing chemicals management regulation, 15 March. *Chemical Watch*. https://chemicalwatch.com/74866/kenya-moves-towards-implementing-chemicals-management-regulation. Accessed 30 March 2019.

Hering, J.G., Dzombak, D.A., Green, S.A., Luthy, R.G., Swackhamer, D. (2014). Engagement at the science-policy interface. *Environmental Science and Technology* 48 (19), 11031-11033. http://doi.org/10.1021/es504225t.

Honduras Secretariat of Natural Resources and Environment (2013). *Policy for the Environmentally Sound Management of Chemical Products in Honduras*. Tegucigalpa: Government of Hounduras.

Independent Evaluation Office of the Global Environment Facility (2018). *Sixth Overall Performance Study of the GEF – The GEF in the Changing Environmental Finance Landscape*. https://www.thegef.org/sites/default/files/council-meeting-documents/GEF.A6.07_OPS6_0.pdf.

International Council of Chemical Associations (2015a). *2015 Responsible Care Status Report*. https://www.icca-chem.org/wp-content/uploads/2015/09/2015-Responsible-Care-Status-Report.pdf.

International Council of Chemical Associations (2015b). *The International Council of Chemical Associations Fifth Update Report on the Implementation Indicators of the Strategic Approach to International Chemicals Management*. Geneva: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/inf/iccm4_inf26_icca_progress_report.pdf.

International Council of Chemical Associations (2019). *2018 Responsible Care® Status Report: The Global Picture*. https://www.icca-chem.org/wp-content/uploads/2019/01/Responsible-Care-Status-Report-2018.pdf.

International Criminal Police Organization (2017a). *Operation 30 Days of Action*: *Final Report*. https://www.interpol.int/Media/Files/Crime-areas/Environmental-crime/Pollution-Crime-Working-Group/The-Final-Report-of-Operation-30-Days-of-Action.

International Criminal Police Organization (2017b). *Operation 30 Days of Action: Key Operational Findings*. https://www.interpol.int/Media/Files/Crime-areas/Environmental-crime/Pollution-Crime-Working-Group/The-Brief-on-Key-Operational-Findings-of-Operation-30-Days-of-Action.

International Labour Organization (2007). Meeting of experts to examine instruments, knowledge, advocacy, technical cooperation and international collaboration as tools with a view to developing a policy framework for hazardous substances. https://www.ilo.org/sector/activities/sectoral-meetings/WCMS_160738/lang--en/index.htm. Accessed 28 August 2018.

International Labour organization (2013). *Safety and Health in the Use of Chemicals at Work*. https://www.ilo.org/wcmsp5/groups/public/@ed_protect/@protrav/@safework/documents/publication/wcms_235085.pdf.

International Panel on Chemical Pollution. (2018). *Thought Starter on a Possible Model for the Science-Policy Interface under the Post 2020 Framework*. Submitted to the second meeting of the intersessional process considering the Strategic Approach and the sound management of chemicals and waste beyond 2020. http://www.saicm.org/Portals/12/documents/meetings/IP2/A%20Thought%20%20Starter%20on%20a%20Possible%20Model%20for%20the%20Science_draft_15March2018_updated.pdf.

International POPs Elimination Network (2018). International SAICM implementation project (ISIP). https://ipen.org/projects/international-saicm-implementation-project-isip. Accessed 11 September 2018.

Inter-Organization Programme for The Sound Management of Chemicals (2019). Data on IOMC indicators of progress in implementing SAICM. *Data Compiled by the IOMC Participating Organizations and Provided Through IOMC Secretariat*.

Ismail, S.N.S., Mohamad, N.S., Karuppiah, K., Abidin, E.Z., Rasdi, I. and Praveena, S.M. (2017). Heavy metals content in low-priced toys. *ARPN Journal of Engineering and Applied Sciences* 12(5). 1499-1509. http://www.arpnjournals.org/jeas/research_papers/rp_2017/jeas_0317_5787.pdf.

Kawanishi, A. (2018). Vietnam launches national chemical database: more than 170,000 substances included. *Chemical Watch*. https://chemicalwatch.com/69376/vietnam-launches-national-chemical-database. Accessed 30 March 2019.

Kazan-Allen, L. (2018). Current asbestos bans. *International Ban Asbestos Secretariat*. http://ibasecretariat.org/alpha_ban_list.php. Accessed 29 November 2018.

Lipman, Z. (2015). Trade in hazardous waste. In *International Environmental Law and the Global South*. Alam, S., Atapattu, S., Gonzalez, C.G. and Razzaque, J. (eds). Cambridge University Press. Chapter 12. 256-276. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2822585.

Mclean, S. and Khadan, J. (2015). *An Assessment of the Performance of CARICOM Extraregional Trade Agreements: An Initial Scoping Exercise*. Santiago: United Nations. https://repositorio.cepal.org/bitstream/handle/11362/37612/5/lcarl455_rev1.pdf.

Molina, M., Zaelke, D., Sarma, K.M., Andersen, S.O., Ramanathan, V. and Kaniaru, D. (2009). Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America* 106 (49), 20616-20621. https://doi.org/10.1073/pnas.0902568106.

Montzka, S.A., Dutton, G.S., Yu, P., Ray, E., Portmann, R.W., Daniel, J.S., Kuijpers, L., Hall, B.D., Mondeel, D., Siso, C., Nance, J.D., Rigby, M., Manning, A.J., Hu, L., Moore, F., Miller, B.R. and Elkins, J.W. (2018). An unexpected and persistent increase in global emissions of ozone-depleting CFC-11. *Nature* 557, 413-417. https://doi.org/10.1038/s41586-018-0106-2.

Morocco Ministry of Health (n.d.). *Cadre Relatif à l'Enregistrement des Produits Cosmétiques et d'Hygiène Corporelle - Circulaire N° 48 DMP/20*. Rabat: Kingdom of Morrocco. https://pharmacie.ma/uploads/pdfs/circulaire_48-DMP-00_.pdf.

Niadu, R. (2017). New life breathed into India's chemical policy plans, 7 June. *Chemical Watch*. https://chemicalwatch.com/56650/new-life-breathed-into-indias-chemical-policy-plans. Accessed 28 August 2018.

Nurick, R. and Touni, E. (2015). *Impact Evaluation of the Quick Start Programme*. Geneva: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/inf/ICCM4_INF5_QSP-evaluation.pdf.

Olley, K., Ross, N. and O'Shea, P. (2016). *IMPEL – TFS Enforcement Actions Project Report 2014 – 2015: Enforcement of the European Waste Shipment Regulation*. Brussels: European Union Network for the Implementation and Enforcement of Environmental Law. https://www.impel.eu/wp-content/uploads/2016/10/IMPEL-Enforcement-Actions-2014-15-FINAL-report.pdf.

Organisation for Economic Cooperation and Development (2015). *Preliminary Analysis of Policy Drivers Influencing Decision Making in Chemicals Management*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2015)21&doclanguage=en.

Organisation for Economic Cooperation and Development (2017). *Active with Latin America and the Caribbean*. http://www.oecd.org/global-relations/Active-with-Latin-America-and-the-Caribbean.pdf.

Organisation for Economic Cooperation and Development (2018a). IOMC toolbox for decision making in chemicals management, 25 May. *Inter-Organization Programme for the Sound Management of Chemicals*. https://iomctoolbox.oecd.org/Default.aspx?idExec=d39e45a0-70e0-47f4-9949-1ec46f320b1b. Accessed 1 June 2018.

Organisation for Economic Cooperation and Development (2018b). DAC list of ODA recipients. http://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/daclist.htm. Accessed 21 November 2018.

Organisation for Economic Cooperation and Development (n.d.). *The OECD Cooperative Chemicals Assessment Programme: An International Programme with Global Reach*. http://www.oecd.org/env/ehs/risk-assessment/CoCAP-flyer.pdf.

Persson, L., Karlsson-Vinkhuyzen, S., Lai, A., Persson, Å. and Fick, S. (2017). The globally harmonized system of classification and labelling of chemicals: explaining the legal implementation gap. *Sustainability* 9(12), 1-14. https://doi.org/10.3390/su9122176.

Rae I. and Gabriel, A. (2012). Saving the ozone layer: why the Montreal Protocol worked, 9 September. https://theconversation.com/saving-the-ozone-layer-why-the-montreal-protocol-worked-9249. Accessed 28 August 2018.

Republic of Ghana (2016). *Hazardous and Electronic Waste Control and Management Act 917*. Accra. http://greenadgh.com/images/documentsrepository/HazardousandElectronicWasteControl.pdf.

Rwanda Ministry of Health (2016). *Ministerial Order Determining the List of Cosmetics Whose Use is Prohibited in Rwanda*. Kigali. https://www.primature.gov.rw/fileadmin/user_upload/documents/Official%20Gazettes/2016_Official_Gazettes/Official_Gazette_no_09_of_29.02.2016.pdf.

Sand, P.H. (2016). *The Effectiveness of Multilateral Environmental Agreements: Theory and Practice.* Joensuu: University of Finland Law School and United Nations Environment Programme. https://www.researchgate.net/publication/311717128_The_Effectiveness_of_Multilateral_Environmental_Agreements_Theory_and_Practice.

Secretariat of the Basel Convention (2011). Development of technical guidelines. http://www.basel.int/Implementation/TechnicalMatters/DevelopmentofTechnicalGuidelines/tabid/2374/Default.aspx. Accessed 4 February 2019.

Secretariat of the Basel Convention (2017). Mid-term evaluation. http://www.basel.int/Implementation/StrategicFramework/Evaluation/Midtermevaluation/tabid/3810/Default.aspx. Accessed 4 February 2019.

Secretariat of the Basel Convention (2019a). Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal. http://www.basel.int/Countries/StatusofRatifications/PartiesSignatories/tabid/4499/Default.aspx. Accessed 2 February 2019.

Secretariat of the Basel Convention (2019b). National defintions of hazardous waste. http://www.basel.int/Countries/NationalDefinitions/NationalDefinitionsofHazardousWastes/tabid/1480/Default.aspx. Accessed 2 February 2019.

Secretariat of the Basel, Rotterdam and Stockholm Conventions (2017). *Decisions Adopted by the Conferences of the Parties to the Basel, Rotterdam and Stockholm Conventions that Make Specific Reference to the Minamata Convention on Mercury*. Geneva: Secretariat of the Minamata Convention on Mercury. http://www.mercuryconvention.org/Portals/11/documents/meetings/COP1/English/1_INF14_BRS_decisions.pdf.

Secretariat of the Basel, Rotterdam and Stockholm Conventions (2018). Synergies among the Basel, Rotterdam and Stockholm Conventions. http://www.brsmeas.org/. Accessed 5 June 2018.

Secretariat of the Minamata Convention on Mercury (2017). *Report of the Conference of the Parties to the Minamata Convention on Mercury on the Work of its First Meeting*. http://www.mercuryconvention.org/Portals/11/documents/meetings/COP1/English/1_29_e_report.pdf.

Secretariat of the Minamata Convention on Mercury (2018). Specific International Programme. http://www.mercuryconvention.org/Implementation/SpecificInternationalProgramme/tabid/6334/language/en-US/Default.aspx. Accessed 11 November 2018.

Secretariat of the Rotterdam Convention (2013). *Information on the Implementation of the Rotterdam Convention*. http://www.pic.int/Portals/5/download.aspx?d=UNEP-FAO-RC-COP.6-4.En.pdf.

Secretariat of the Rotterdam Convention (2019). Status of ratifications of the Rotterdam Convention. http://www.pic.int/Countries/Statusofratifications/tabid/1072/language/en-US/Default.aspx. Accessed 4 February 2019.

Secretariat of the Stockholm Convention (2008). Convention text. http://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx. Accessed 27 August 2018.

Secretariat of the Stockholm Convention (2009). *Global Monitoring Report Under the Global Monitoring Plan for Effectiveness Evaluation*. http://chm.pops.int/Implementation/GlobalMonitoringPlan/MonitoringReports/tabid/525/Default.aspx.

Secretariat of the Stockholm Convention (2017). Outcomes of the effectiveness evaluation of the Stockholm Convention. http://chm.pops.int/Implementation/EffectivenessEvaluation/Outcomes/tabid/5559/Default.aspx. Accessed 11 September 2018.

Secretariat of the Stockholm Convention (2019a). Status of ratifications of the Stockholm Convention. http://chm.pops.int/Countries/StatusofRatifications/PartiesandSignatoires/tabid/4500/Default.aspx. Accessed 4 February 2019

Secretariat of the Stockholm Convention (2019b). National Implementation Plans. http://chm.pops.int/Implementation/NationalImplementationPlans/NIPTransmission/tabid/253/Default.aspx. Accessed 4 February 2019.

Secretariat of the Strategic Approach to International Chemicals Management (2009a). *Proposal on Modalities for Reporting by Stakeholders on Progress in Implementation*. http://www.saicm.org/Portals/12/documents/meetings/ICCM2/doc/ICCM2%203%20reporting%20E.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2009b). *Emerging Policy Issues*. http://www.saicm.org/Portals/12/documents/meetings/ICCM2/doc/ICCM2%2010%20emerging%20issues%20E.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2011). *Draft Baseline Estimates Report (2006-2008): Progress in Implementation of the Strategic Approach to International Chemicals Management Progress*. http://www.saicm.org/Portals/12/documents/meetings/OEWG1/inf/OEWG1%20INF1_Baseline%20report.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2012). *Progress in Implementation of the Strategic Approach to International Chemicals Management for 2009 and 2010*. http://www.saicm.org/Portals/12/documents/meetings/ICCM3/inf/ICCM_3_INF6_first%20progress%20report_Final.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2014). *Progress in Strategic Approach Implementation for 2011-2013*. http://www.saicm.org/Portals/12/documents/meetings/OEWG2/inf/k1403579-eowg2-inf4.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2015a). *Summary Report on Progress in the Implementation of the Strategic Approach for the Period 2011-2013*. http://www.saicm.org/Portals/12/Documents/reporting/K1502325 SAICM-ICCM4-3-summary-second-progress-report.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2015b). *Overall Orientation and Guidance for Achieving the 2020 Goal of Sound Management of Chemicals*. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/doc/K1501995%20SAICM-ICCM4-6-e.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2015c). *The Integrated Approach to Financing of Sound Management of Chemicals and Wastes: UNEP Case Studies on Mainstreaming*. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/inf/ICCM4_INF12_UNEP%20Mainstreaming.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2015d). *Report of the United Nations Environment Programme on the Integrated Approach to Financing of Sound Management of Chemicals and Waste: Industry Involvement*. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/inf/K1502922-INF13%20UNEP%20Industry.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2018a). *Regional Meeting on the Strategic Approach to International Chemicals Management: Status of Input to the 2014-2016 Strategic Approach Report on Progress*. http://www.saicm.org/Portals/12/documents/meetings/ICCM5/Documents%20common%20to%20all%20regional%20meetings%202018/RM2018_1_Reporting_.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2018b). *Independent Evaluation of the Strategic Approach from 2006-2015 Draft Report.* http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_4_Independent_Evaluation.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2018c). *Financing the Sound Management of Chemicals and Waste beyond 2020*. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_9_Finance.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2018d). Quick Start Programme. http://www.saicm.org/Implementation/QuickStartProgramme. Accessed 11 September 2018.

Secretariat of the Strategic Approach to International Chemicals Management (2018e). *Summary Perspectives on SAICM and the Sound Management of Chemicals and Waste beyond 2020 – Sixth SAICM African Regional Meeting*. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_19_AFR_Summary_Beyond2020.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2018f). *Summary of Different Perspectives on SAICM and the Sound Management of Chemicals and Waste beyond 2020 – Fifth SAICM Asia-Pacific Regional Meeting*. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_18_AP_Summary_Beyond2020.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2018g). *Summary of Different Perspectives on SAICM and the Sound Management of Chemicals and Waste Beyond 2020 – Sixth SAICM Central and Eastern European Regional Meeting*. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_17_CEE_Summary_Beyond2020.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2019a). *Paper by the Co-Chairs of the Intersessional Process on the Strategic Approach to International Chemicals Management and the Sound Management of Chemicals and Waste Beyond 2020.* http://www.saicm.org/Portals/12/Documents/meetings/OEWG3/doc/K1900262-SAICM-OEWG3-4-Co-Chairs-Paper-ADVANCE.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2019b). *Progress in Strategic Approach Implementation for 2014 - 2016*. http://www.saicm.org/Portals/12/Documents/meetings/OEWG3/inf/OEWG3-INF-4-2014-16-third-Progress-Report-.pdf.

Secretariat of the Strategic Strategic Approach to International Chemicals Management, United Nations Environment Programme and World Health Organization (2006). *Strategic Approach to International Chemicals Management: SAICM Texts and Resolutions of the International Conference on Chemicals Management*. Geneva: United Nations Environment Programme. https://sustainabledevelopment.un.org/content/documents/SAICM_publication_ENG.pdf.

Secretariat of the Vienna Convention and its Montreal Protocol (2018). Ozone Secretariat: country data. https://ozone.unep.org/countries/data. Accessed 11 September 2018.

Seelarbokus, C.B. (2014). Assessing the effectiveness of international environmental agreements (IEAs): demystifying the issue of data unavailability. *SAGE Open* 4(1), 1-18. https://doi.org/10.1177/2158244014521820.

Sistema de Informacion Ambiental del Mercosur (n.d.). Substances and chemical products. https://ambiente.mercosur.int/p_68.t_40/SUSTANCIAS_Y_PRODUCTOS_QUIMICOS.html. Accessed 11 September 2018.

Slater, M. (2015). Banned on Alibaba – gold suppliers blacklist, 21 January. *China Checkup*. https://www.chinacheckup.com/blogs/articles/banned-on-alibaba. Accessed 19 February 2019.

Stieger, G., Scheringer, M., Ng, C.A. and Hungerbühler, K. (2014). Assessing the persistence, bioaccumulation potential and toxicity of brominated flame retardants: data availability and quality for 36 alternative brominated flame retardants. *Chemosphere* 116, 118-123. https://doi.org/10.1016/j.chemosphere.2014.01.083.

Strempel, S., Scheringer, M., Ng, C.A. and Hungerbühler, K. (2012). Screening for PBT chemicals among the 'existing' and 'new' chemicals of the EU. *Environmental Science & Technology* 46(11), 5680–5687. https://doi.org/10.1021/es3002713.

Stringer, L. (2017). South Africa's chemicals bill is "off the table", 21 March. https://chemicalwatch.com/54581/south-africas-chemicals-bill-is-off-the-table. Accessed 28 August 2018.

Swedish Chemicals Agency (2016). *Towards a Non-Toxic South-East Asia*. https://www.kemi.se/global/broschyrer/towards-a-non-toxic-south-east-asia.pdf.

Swedish Chemicals Agency (2017a). *The Swedish Chemicals Agency's Analyses in Conjunction with Enforcement 2016*. https://www.kemi.se/global/tillsyns-pm/2017/enforcement-7-17-the-swedish-chemicals-agencys-analyses-in-conjunction-with-enforcement-2016.pdf.

Swedish Chemicals Agency (2017b). Enforcement projects. https://www.kemi.se/en/ inspectors/enforcement-projects. Accessed 11 September 2018.

United Nations (2002). *Plan of Implementation of the World Summit on Sustainable Development*. Johannesburg. http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/WSSD_PlanImpl.pdf.

United Nations (2005) *Building Block Approach: Guidance and Implementation.* https://www.unece.org/fileadmin/DAM/trans/doc/2005/ac10c4/ST-SG-AC10-C4-2005-06e.doc.

United Nations (2011). Phase-out of leaded petrol brings huge health and cost benefits – UN-backed study, 27 October. *UN News*. https://news.un.org/en/story/2011/10/393292-phase-out-leaded-petrol-brings-huge-health-and-cost-benefits-un-backed-study#.UZdkooJAsR4. Accessed 4 February 2019.

United Nations Comtrade (2018). UN Comtrade database: international trade statistics. https://comtrade.un.org/data. Accessed 7 June 2018.

United Nations Environment Programme (2015). *The Montreal Protocol and Human Health: How Global Action Protects Us from the Ravages of Ultraviolet Radiation*. http://www.unep.fr/ozonaction/information/mmcfiles/7738-e-TheMontrealProtocolandHumanHealth.pdf.

United Nations Environment Programme (2016). *Report on the Implementation of the Integrated Approach to Financing Sound Management of Chemicals and Waste*. https://www.unenvironment.org/resources/report/unepea2inf18-report-implementation-integrated-approach-financing-sound-management.

United Nations Environment Programme (2017). *Lead Petrol Phase-out: Global Status as at March 2017*. https://wedocs.unep.org/bitstream/handle/20.500.11822/17542/MapWorldLead_March2017.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2018a). Implementation and compliance committee. *Minimata Convention on Mercury*. http://www.mercuryconvention.org/Implementation/ImplementationandComplianceCommittee/tabid/6331/language/en-US/Default.aspx. Accessed 11 September 2018.

United Nations Environment Programme (2018b). *Launch of the Global Montreal Protocol Award for Customs and Enforcement Officers: First Inter-Regional Thematic Workshop and Regional Network Meetings of the Ten Ozone Networks*. http://www.unep.fr/ozonaction/information/mmcfiles/7930-e-Global_MP_Award_for_Customs_Enforcement_Officers.pdf.

United Nations Environment Programme (2019a). National Action Plans. http://web.unep.org/globalmercurypartnership/our-work/reducing-mercury-artisanal-and-small-scale-gold-mining-asgm/national-action-plans. Accessed 4 February 2019.

United Nations Environment Programme (2019b). *Illegal Trade In Chemicals*. In print.

United Nations Environment Programme and International Council of Chemical Associations (2019). *Knowledge Management and Information Sharing for the Sound Management of Industrial Chemicals*. Montevideo: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/Documents/meetings/OEWG3/inf/OEWG3-INF-28-KMI.pdf.

United Nations Environment Programme and Secretariat of the Stockholm Convention (2017a). *Second Global Monitoring Report: Global Monitoring Plan for Persistent Organic Pollutants*. Geneva: Secretariat of the Stockholm Convention. http://chm.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP8/tabid/5309/Default.aspx.

United Nations Environment Programme and Secretariat of the Stockholm Convention (2017b). *Report on the Effectiveness Evaluation of the Stockholm Convention on Persistent Organic Pollutants*. Geneva: Secretariat of the Stockholm Convention. http://chm.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP8/tabid/5309/Default.aspx.

United Nations Institute for Training and Research (2004). *Developing and Sustaining an Integrated National Programme for Sound Chemicals Management: Guidance Document*. http://cwm.unitar.org/national-profiles/publications/cw/inp/inp_gd_2004-05_(13_may2004_red_r1).pdf.

United Nations Institute for Training and Research (2018a). National profile homepage: national profiles to assess infrastructure and capacity needs for chemicals management. http://cwm.unitar.org/national-profiles/nphomepage/np3_region.aspx. Accessed 29 August 2018.

United Nations Institute for Training and Research (2018b). UNITAR PRTR platform: what is a pollutant release and transfer register? http://prtr.unitar.org/site/unique/1126. Accessed 28 August 2018.

United States Congress (2016). *The Frank R. Lautenberg Chemical Safety for the 21st Century Act*. Public Law 114-182 - 114th Congress. https://www.congress.gov/114/plaws/publ182/PLAW-114publ182.pdf.

United States Environmental Protection Agency (2018a). Recent international developments under the Montreal Protocol, 26 September. https://www.epa.gov/ozone-layer-protection/recent-international-developments-under-montreal-protocol. Accessed 20 November 2018.

United States Environmental Protection Agency (2018b). Assessing and managing chemicals under TSCA: risk evaluations for existing chemicals under TSCA, 14 November. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluations-existing-chemicals-under-tsca. Accessed 20 November 2018.

United States Environmental Protection Agency (2018c). EPA settles with Amazon for distributions of illegal pesticides: agreement will help protect online consumers, 15 February. https://www.epa.gov/newsreleases/epa-settles-amazon-distributions-illegal-pesticides. Accessed 19 February 2019.

Urho, N. (2018). *Options for Effective Governance of the Beyond-2020 Framework for Sound Management of Chemicals and Waste: Lessons Learned from Other Regimes*. Boston, MA: Center for Governance and Sustainability, University of Massachusetts Boston. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_14_Governance_CGS_f.pdf.

Venugopal, A. and Bose, N. (2018). New York sues Target, Walmart over lead contaminated toys, 13 December. *Reuters*. https://www.reuters.com/article/us-new-york-lawsuit-toys/new-york-sues-target-walmart-over-lead-contaminated-toys-idUSKBN1OC2PC. Accessed 19 February 2019.

World Customs Organization (2014). Tonnes of illegal waste seized under Operation Demeter III, 20 January. http://www.wcoomd.org/en/media/newsroom/2014/january/tonnes-of-illegal-waste-seized-under-operation-demeter-iii.aspx. Accessed 19 February 2019.

World Health Organization (2017). Global health observatory (GHO) data: poisons centres. http://www.who.int/gho/phe/chemical_safety/poisons_centres/en/. Accessed 28 August 2018.

World Health Organization (2018a). IHR core capacities implementation status: Chemical. http://www.who.int/gho/ihr/monitoring/chemical/en/index1.html. Accessed 27 August 2018.

World Health Organization (2018b). International programme on chemical safety: poisoning prevention and management. http://www.who.int/ipcs/poisons/en/. Accessed 4 July 2016.

World Health Organization (2018c). Database of IOMC activities in countries. *Inter-Organization Programme For The Sound Management of Chemicals*. http://www.who.int/iomc/activity/poactivities/en/. Accessed 11 September 2018.

World Health Organization, United Nations Environment Programme, Basel Rotterdam and Stockholm Conventions' Secretariat and Organisation for Economic Cooperation and Development (2018). *Existing Science-Policy Interfaces for International Chemicals and Waste Issues*. Stockholm: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_12_Science_Policy_Interface.pdf.

World Meteorological Organization (2018a). *Executive Summary: Scientific Assessment of Ozone Depletion: 2018*. Global Ozone Research and Monitoring Project – Report No. 58. http://conf.montreal-protocol.org/meeting/oewg/oewg-41/presession/Background%20Documents%20are%20available%20in%20English%20only/SAP-2018-Assessment-report-ES-rev.pdf.

World Meteorological Organization (2018b). *Scientific Assessment of Ozone Depletion*. Global Ozone Research and Monitoring Project. https://ozone.unep.org/sites/default/files/Assessment_Panel/SAP-2018-Assessment-report.pdf.

World Meteorological Organization (2019). Scientific assessment confirms start of recovery of ozone layer, 8 February. https://public.wmo.int/en/media/news/scientific-assessment-confirms-start-of-recovery-of-ozone-layer. Accessed 26 March 2019.

Young, O.R. (2011). Effectiveness of international environmental regimes: existing knowledge, cutting-edge themes, and research strategies. *Proceedings of the National Academy of Sciences of the United States* 108(50) 19853-19860. https://doi.org/10.1073/pnas.1111690108.

Zaman, R. (2016). Chemicals management laws continue to develop in Asia, 31 May. *Enhesa*. http://www.enhesa.com/blog/chemicals-management-laws-continue-develop-asia. Accessed 28 August 2018.

## Chapter 4

Aizer, A., Currie, J., Simon, P. and Vivier, P. (2018). Do low levels of blood lead reduce children's future test scores? *American Economic Journal: Applied Economics* 10(1), 307-341. https://doi.org/10.1257/app.20160404.

Akhter, M.N., Chakaborty, T.K., Ghosh, P., Jahan, S., Ghosh, G.C. and Hossain, S.A. (2016). Assessment of the using patterns of pesticides and its impact on farmers health in the Jhenidah District of Bangladesh. *American Journal of Environmental Protection* 5(5), 139-144. http://doi.org/10.11648/j.ajep.20160505.16.

Andersson, N., Arena, M., Auteri, D., Barmaz, S., Grignard, E., Kienzler, A., Lepper, P., Lostia, A.M., Munn, S., Parra Morte, J.M., Pellizzato, F., Tarazona, J., Terron, A., Van der Linden, S. (2018). Guidance for the identification of endocrine disruptors in the context of regulations (EU) no 528/2012 and (EC) no 1107/2009. *EFSA Journal* 16(6). https://doi.org/10.2903/j.efsa.2018.5311.

Andrade-Rivas, F. and Rother, H.-A. (2015). Chemical exposure reduction: factors impacting on South African herbicide sprayers' personal protective equipment compliance and high risk work practices. *Environmental Research* 142, 34-45. https://doi.org/10.1016/j.envres.2015.05.028.

Anh, H.Q., Nam, V.D., Tri, T.M., Ha, N.M., Ngoc, N.T., Mai, P.T.N. , Anh, D.H., Minh, N.H., Tuan, N.A. and Minh, T.B. (2017). Polybrominated diphenyl ethers in plastic products, indoor dust, sediment and fish from informal e-waste recycling sites in Vietnam: a comprehensive assessment of contamination, accumulation pattern, emissions, and human exposure. *Environmental Geochemistry and Health* 39(4), 935-954. https://doi.org/10.1007/s10653-016-9865-6.

Ankley, G.T., Bennett, R.S., Erickson, R.J., Hoff, D.J., Hornung, M.W., Johnson, R.D., Mount, D.R., Nichols, J.W., Russom, C.L., Schmieder, P.K., Serrrano, J.A., Tietge, J.E. and Villeneuve, D.L. (2010). Adverse outcome pathways: a conceptual framework to support ecotoxicology research and risk assessment. *Environmental Toxicology and Chemistry* 29(3), 730-741. https://doi.org/10.1002/etc.34.

Annamalai, J. and Namasivayam, V. (2015). Endocrine disrupting chemicals in the atmosphere: their effects on humans and wildlife. *Environment International* 76, 78-97. https://doi.org/10.1016/J.ENVINT.2014.12.006.

Attina, T.M. and Trasande, L. (2013). Economic costs of childhood lead exposure in low- and middle-income countries. *Environmental Health Perspectives* 121(9), 1097-1102. https://doi.org/10.1289/ehp.1206424.

Australian Department of Health (2018a). Per- and poly-fluorinated substances (PFAS). *National Industrial Chemicals Notification and Assessment Scheme*. https://www.nicnas.gov.au/chemical-information/Topics-of-interest2/subjects/Per-and-poly-fluorinated-alkyl-substances. Accessed 24 August 2018.

Australian Department of Health (2018b). Inventory multi-tiered assessment and prioritisation (IMAP). *National Industrial Chemicals Notification and Assessment Scheme*. https://www.nicnas.gov.au/chemical-information/imap-assessments. Accessed 13 June 2018.

Awasthi, A.K., Zeng, X. and Li, J. (2016). Relationship between e-waste recycling and human health risk in India: a critical review. *Environmental Science and Pollution Research* 23(12), 11509-11532. https://doi.org/10.1007/s11356-016-6085-7.

Baines, D., Wilton, E., Pawluk, A., de Gorter, M. and Chomistek, N. (2017). Neonicotinoids act like endocrine disrupting chemicals in newly-emerged bees and winter bees. *Scientific Reports* 7(1), 10979. https://doi.org/10.1038/s41598-017-10489-6

Baldé, C.P., Forti V., Gray, V., Kuehr, R. and Stegmann, P. (2017). *The Global E-waste Monitor 2017: Quantities, Flows, and Resources*. Bonn, Geneva and Vienna: United Nations University, International Telecommunication Union and the International Solid Waste Association. https://collections.unu.edu/eserv/UNU:6341/Global-E-waste_Monitor_2017__electronic_single_pages_.pdf.

Beausoleil, C., Ormsby, J.-N., Gies, A., Hass, U., Heindel, J.J., Holmer, M.L., Nielsen, P.J., Munn, S. and Schoenfelder, G. (2013). Low dose effects and non-monotonic dose responses for endocrine active chemicals: science to practice workshop: workshop summary. *Chemosphere* 93(6), 847-856. https://doi.org/10.1016/J.CHEMOSPHERE.2013.06.043.

Becker, R.A., Ankley, G.T., Edwards, S.W., Kennedy, S.W., Linkov, I., Meek, B., Sachana, M., Segner, H., Van Der Burg, B., Villeneuve, D.L., Watanabe, H. and Barton-Maclaren, T.S. (2015). Increasing scientific confidence in adverse outcome pathways: application of tailored Bradford-Hill considerations for evaluating weight of evidence. *Regulatory Toxicology and Pharmacology* 72(3), 514-537. https://doi.org/10.1016/J.YRTPH.2015.04.004.

Beek, T. aus der, Weber, F.-A., Bergmann, A., Grüttner, G. and Carius, A. (2016a). *Pharmaceuticals in the Environment: Global Occurrence and Potential Cooperative Action Under the Strategic Approach to International Chemicals Management (SAICM)*. Hickmann, S. (ed.). Dessau-Roßlau: German Environment Agency. https://www.umweltbundesamt.de/en/publikationen/pharmaceuticals-in-the-environment-global.

Beek, T. aus der, Weber, F.-A., Bergmann, A., Hickmann, S., Ebert, I., Hein, A. and Küster, A. (2016b). Pharmaceuticals in the environment – global occurrences and perspectives. *Environmental Toxicology and Chemistry* 35(4), 823-835. https://doi.org/10.1002/etc.3339.

Behera, S.K., Kim, H.W., Oh, J.-E. and Park, H.-S. (2011). Occurrence and removal of antibiotics, hormones and several other pharmaceuticals in wastewater treatment plants of the largest industrial city of Korea. *Science of the Total Environment* 409(20), 4351-4360. https://doi.org/10.1016/J.SCITOTENV.2011.07.015.

Bergans (n.d.). How we work with the PFAS challenge. https://www.bergans.com/About-us/CSR/PFAS. Accessed 13 June 2018.

Bergman, Å., Heindel, J., Jobling, S., Kidd, K. and Zoeller, R.T. (eds.) (2013). *State of the Science on Endocrine Disrupting Chemicals-2012: An Assessment of the State of the Science of Endocrine Disruptors Prepared by a Group of Experts for the United Nations Environment Programme*. Geneva: United Nations Environment Programme and the World Health Organization. http://www.who.int/ceh/publications/endocrine/en/.

Berkner, S., Konradi, S. and Schönfeld, J. (2014). Antibiotic resistance and the environment – there and back again. *Society & Society Series on Science and Drugs* 15(7), 740-744. https://doi.org/10.15252/embr.201438978.

BIO Intelligence Service (2013). *Study on the Environmental Risks of Medicinal Products, Final Report Prepared for Executive Agency for Health and Consumers*. https://ec.europa.eu/health/sites/health/files/files/environment/study_environment.pdf.

Birnbaum, L.S. and Grandjean, P. (2015). Alternatives to PFASs: perspectives on the science. *Environmental Health Perspectives* 123(5), 104-105. https://doi.org/10.1289/ehp.1509944.

Blair, B., Zimny-Schmitt, D. and Rudd, M.A. (2017). U.S. news media coverage of pharmaceutical pollution in the aquatic environment: a content analysis of the problems and solutions presented by actors. *Environmental Management* 60(2), 314-322. https://doi.org/10.1007/s00267-017-0881-9.

Blum, A., Balan, S.A., Scheringer, M., Trier, X., Goldenman, G., Cousins, I.T., Diamond, M., Fletcher, T., Higgins, C., Lindeman, A.E., Peaslee, G., de Voogt, P., Wang, Z. and Weber, R. (2015). The Madrid Statement on Poly- and Perfluoroalkyl Substances (PFASs). *Environmental Health Perspectives* 123(5), A107-A111. https://doi.org/10.1289/ehp.1509934.

Boix, C., Ibáñez, M., Sancho, J. V., Parsons, J.R., Voogt, P. de and Hernández, F. (2016). Biotransformation of pharmaceuticals in surface water and during waste water treatment: identification and occurrence of transformation products. *Journal of Hazardous Materials* 302, 175-187. https://doi.org/10.1016/j.jhazmat.2015.09.053.

Borg, D., Ivarsson, J., Andersson, A. and Moore, G. (2017). *Nordic Workshop on PFASs Outcomes*. Stockholm: Nordic Council of Ministers. http://dx.doi.org/10.6027/NA2017-913.

Borges, B.J.P., Carminati, L.S., Fernandes, P.M.B. and Fernandes, A.A.R. (2018). Regulatory framework of nanopharmaceuticals in developing countries: an analysis of the current rules in Brazil. *Inorganic Frameworks as Smart Nanomedicines* 605-639. https://doi.org/10.1016/B978-0-12-813661-4.00014-6.

Bound, J.P. and Voulvoulis, N. (2004). Pharmaceuticals in the aquatic environment––a comparison of risk assessment strategies. *Chemosphere* 56(11), 1143-1155. https://doi.org/10.1016/j.chemosphere.2004.05.010.

Boxall, A.B.A., Rudd, M.A., Brooks, B.W., Caldwell, D.J., Choi, K., Hickmann, S., Innes, E., Ostapyk, K., Staveley, J.P., Verslycke, T., Ankley, G.T., Beazley, K.F., Belanger, S.E., Berninger, J.P., Carriquiriborde, P., Coors, A., DeLeo, P.C., Dyer, S.D., Ericson, J.F., Gagné, F., Giesy, J.P., Gouin, T., Hallstrom, L., Karlsson, M. V., Larsson, D.G.J., Lazorchak, J.M., Mastrocco, F., McLaughlin, A., McMaster, M.E., Meyerhoff, R.D., Moore, R., Parrott, J.L., Snape, J.R., Murray-Smith, R., Servos, M.R., Sibley, P.K., Straub, J.O., Szabo, N.D., Topp, E., Tetreault, G.R., Trudeau, V.L. and Van Der Kraak, G. (2012). Pharmaceuticals and personal care products in the environment: what are the big questions? *Environmental Health Perspectives* 120(9), 1221-1229. https://doi.org/10.1289/ehp.1104477.

Brazilian Ministry of Foreign Affairs (2017). Personal response to request for information, 24 February.

Brendel, S., Fetter, É., Staude, C., Vierke, L. and Biegel-Engler, A. (2018). Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. *Environmental Sciences Europe* 30(1), 9. https://doi.org/10.1186/s12302-018-0134-4.

Brühl, C.A., Schmidt, T., Pieper, S. and Alscher, A. (2013). Terrestrial pesticide exposure of amphibians: an underestimated cause of global decline? *Scientific Reports* 3(1), 1135. https://doi.org/10.1038/srep01135.

Buchberger, W.W. (2011). Current approaches to trace analysis of pharmaceuticals and personal care products in the environment. *Journal of Chromatography A* 1218(4), 603-618. https://doi.org/10.1016/J.CHROMA.2010.10.040.

Casey, M.J. and Wong, P. (2017). Global supply chains are about to get better, thanks to blockchain, 13 March. *Harvard Business Review*. https://hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain. Accessed 12 June 2018.

Cecere, G. and Martinelli, A. (2017). Drivers of knowledge accumulation in electronic waste management: an analysis of publication data. *Research Policy* 46(5), 925-938. https://doi.org/10.1016/J.RESPOL.2017.03.005.

Center for International Environmental Law (2014). *Nanomaterials Definition Fact Sheet*. http://www.ciel.org/Publications/Nano_definition_Nov2014.pdf.

Chakraborty, P., Selvaraj, S., Nakamura, M., Prithiviraj, B., Cincinelli, A. and Bang, J.J. (2018). PCBs and PCDD/Fs in soil from informal e-waste recycling sites and open dumpsites in India: levels, congener profiles and health risk assessment. *Science of the Total Environment* 621, 930-938. https://doi.org/10.1016/J.SCITOTENV.2017.11.083.

Chemours (2016). *Teflon PTFE DISP 30LX Fluoroplastic Dispersion Product Information*. https://www.chemours.com/Teflon_Industrial/en_US/assets/downloads/teflon-ptfe-disp-30lx-product-information.pdf.

Chemours (2018). Teflon EcoElite™ renewably sourced non-fluorinated water repellent. https://www.chemours.com/Teflon_Fabric_Protector/en_US/products/teflon_ecoelite.html#. Accessed 28 March 2018.

Chiang, S., Cox, C. and Levin, J. (2018). *Avoiding Hidden Hazards: A Purchaser's Guide to Safer Foodware*. https://www.ceh.org/wp-content/uploads/CEH-Disposable-Foodware-Report-final-1.31.pdf.

Chou, H.-M., Kao, C.-C., Pin Chuang, K., Lin, C., Shy, C.-G., Chen, R.-F., Tsai, C.-C., Chuang, C.-Y., Cheng, Y.-C., Chen, C.-C. and Chao, H.-R. (2016). Levels of polybrominated diphenyl ethers in air-conditioner filter dust used to assess health risks in clinic and electronic plant employees. *Aerosol and Air Quality Research* 16, 184-194. https://doi.org/10.4209/aaqr.2015.09.0541.

Cobbing, M. and Dowdall, T. (2014). *Green Gadgets: Designing the Future*. Amsterdam: Greenpeace International. https://www.greenpeace.org/archive-international/Global/international/publications/toxics/2014/Green%20Gadgets.pdf.

Cobbing, M., Campione, C. and Kopp, M. (2017). *PFC Revolution in the Outdoor Sector*. Zurich: Greenpeace. https://www.greenpeace.org/archive-international/Global/international/publications/detox/2017/PFC-Revolution-in-Outdoor-Sector.pdf.

Congress of the United States (2009). *H.R.2420 – Environmental Design of Electrical Equipment Act (EDEE) Act*. https://www.congress.gov/bill/111th-congress/house-bill/2420/text.

Conolly, R.B., Ankley, G.T., Cheng, W., Mayo, M.L., Miller, D.H., Perkins, E.J., Villeneuve, D.L. and Watanabe, K.H. (2017). Quantitative adverse outcome pathways and their application to predictive toxicology. *Environmental Science & Technology* 51(8), 4661-4672. https://doi.org/10.1021/acs.est.6b06230.

Cook, G. and Jardim, E. (2017). *Guide to Greener Electronics 2017*. Bach, N. (ed.). Washington, D.C.: Greenpeace. https://www.greenpeace.org/usa/wp-content/uploads/2017/10/Guide-to-Greener-Electronics-2017.pdf.

Cosmetics Europe (2018). *Understanding the Label*. https://www.cosmeticseurope.eu/cosmetic-products/understanding-label/. Accessed 17 November 2017.

Cousins, I.T., Vestergren, R., Wang, Z., Scheringer, M. and McLachlan, M.S. (2016). The precautionary principle and chemicals management: the example of perfluoroalkyl acids in groundwater. *Environment International* 94, 331-340. https://doi.org/10.1016/J.ENVINT.2016.04.044.

CropLife International (2018). *Ensuring the Sound Management of Pesticides*. Stockholm: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_11_Croplife_PesticideManagement_f.pdf.

Curl, O. (2013). Firms phase out lead from paints. *Chemical Watch*, March. https://chemicalwatch.com/14163/firms-phase-out-lead-from-paints. Accessed 11 June 2018.

CVS Health (2017). CVS Health takes major step to address chemicals of consumer concern, 19 April. https://cvshealth.com/newsroom/press-releases/cvs-health-takes-major-step-to-address-chemicals-of-consumer-concern. Accessed 14 August 2018.

Dalvie, M.A., Rother, H.A. and London, L. (2014). Chemical hazard communication comprehensibility in South Africa: safety implications for the adoption of the globally harmonised system of classification and labelling of chemicals. *Safety Science* 61, 51-58. https://doi.org/10.1016/j.ssci.2013.07.013.

Danish Environmental Protection Agency (2017). *Exposure of Children and Unborn Children to Selected Chemical Substances*. Larsen, P.B., Boberg, J., Poulsen, P.B., Mørck, T.A., Boyd, H.B., Andersen, D.N., Axelstad, M. and Hass, U. (eds.). https://www2.mst.dk/Udgiv/publications/2017/04/978-87-93529-84-7.pdf.

Daughton, C.G. (2002). Environmental stewardship and drugs as pollutants. *Lancet* 360(9339), 1035-1036. https://doi.org/10.1016/S0140-6736(02)11176-7.

Dekkers, S., Oomen, A.G., Bleeker, E.A.J., Vandebriel, R.J., Micheletti, C., Cabellos, J., Janer, G., Fuentes, N., Vázquez-Campos, S., Borges, T., Silva, M.J., Prina-Mello, A., Movia, D., Nesslany, F., Ribeiro, A.R., Leite, P.E., Groenewold, M., Cassee, F.R., Sips, A.J.A.M., Dijkzeul, A., van Teunenbroek, T. and Wijnhoven, S.W.P. (2016). Towards a nanospecific approach for risk assessment. *Regulatory Toxicology and Pharmacology* 80, 46-59. https://doi.org/10.1016/J.YRTPH.2016.05.037.

Dewalt, F.G., Cox, D.C., O'Haver, R., Salatino, B., Holmes, D., Ashley, P.J., Pinzer, E.A., Friedman, W., Marker, D., Viet, S.M. and Fraser, A. (2015). Prevalence of lead hazards and soil arsenic in U.S. housing. *Journal of Environmental Health* 78(5), 22-29. http://www.ncbi.nlm.nih.gov/pubmed/26738315.

DiGangi, J. (2018). *Establishing a Pollutant Release and Transfer Register is Critical for China's Hazardous Chemicals Management*. http://ipen.org/sites/default/files/documents/PRTR%20report%20press%20release_EN_Final.pdf.

Ding, Y., Kuhlbusch, T.A.J., Van Tongeren, M., Jiménez, A.S., Tuinman, I., Chen, R., Alvarez, I.L., Mikolajczyk, U., Nickel, C., Meyer, J., Kaminski, H., Wohlleben, W., Stahlmecke, B., Clavaguera, S. and Riediker, M. (2017). Airborne engineered nanomaterials in the workplace – a review of release and worker exposure during nanomaterial production and handling processes. *Journal of Hazardous Materials* 322, 17-28. https://doi.org/10.1016/J.JHAZMAT.2016.04.075.

Donaldson, K. and Poland, C.A. (2013). Nanotoxicity: challenging the myth of nano-specific toxicity. *Current Opinion in Biotechnology* 24(4), 724-734. https://doi.org/10.1016/J.COPBIO.2013.05.003.

Donnachie, R.L., Johnson, A.C. and Sumpter, J.P. (2016). A rational approach to selecting and ranking some pharmaceuticals of concern for the aquatic environment and their relative importance compared with other chemicals. *Environmental Toxicology and Chemistry* 35(4), 1021-1027. https://doi.org/10.1002/etc.3165.

Duan, H., Li, J., Liu, Y., Yamazaki, N. and Jiang, W. (2011). Characterization and inventory of PCDD/Fs and PBDD/Fs emissions from the incineration of waste printed circuit board. *Environmental Science & Technology* 45(15), 6322-6328. https://doi.org/10.1021/es2007403.

Eguchi, A., Nomiyama, K., Devanathan, G., Subramanian, A., Bulbule, K.A., Parthasarathy, P., Takahashi, S. and Tanabe, S. (2012). Different profiles of anthropogenic and naturally produced organohalogen compounds in serum from residents living near a coastal area and e-waste recycling workers in India. *Environment International* 47, 8-16. https://doi.org/10.1016/J.ENVINT.2012.05.003.

Elibariki, R. and Maguta, M.M. (2017). Status of pesticides pollution in Tanzania – a review. *Chemosphere* 178, 154-164. https://doi.org/10.1016/J.CHEMOSPHERE.2017.03.036.

Etchevers, A., Le Tertre, A., Lucas, J.-P., Bretin, P., Oulhote, Y., Le Bot, B. and Glorennec, P. (2015). Environmental determinants of different blood lead levels in children: a quantile analysis from a nationwide survey. *Environment International* 74, 152-159. https://doi.org/10.1016/j.envint.2014.10.007.

European Chemicals Agency (2017). *Agreement of the Member State Committee on the Identification of Perfluorohexane-1-Sulphonic Acid and Its Salts as Substances of Very High Concern According to Articles 57 and 59 of Regulation (EC) 1907/2006*. https://echa.europa.eu/documents/10162/fdc986a0-7479-245a-b64a-7724d1ee760c.

European Chemicals Agency (2018). New database on candidate list substances in articles by 2021, 11 July. https://echa.europa.eu/nl/-/new-database-on-candidate-list-substances-in-articles-by-2021. Accessed 30 December 2018.

European Commission (2000). Directive 2000/60/EC Of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy. *Official Journal of the European Communities* L 327(2), 1-72. https://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF.

European Commission (2004). Directive 2004/28/EC of the European Parliament and of the Council of 31 March 2004 amending Directive 2001/82/EC on the community code relating to veterinary medicinal products. *Official Journal of the European Union* L 136(58), 1-27. https://ec.europa.eu/health/sites/health/files/files/eudralex/vol-5/dir_2004_28/dir_2004_28_en.pdf.

European Commission (2006). Regulation (EC) No. 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the registration, evaluation, authorisation and restriction of chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999. *Official Journal of the European Union* L 396, 3-280. https://doi.org/10.04.2014.

European Commission (2009a). Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys. *Official Journal of the European Union* L 170(2), 1-37. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:170:0001:0037:en:PDF.

European Commission (2009b). Regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on cosmetic products. *Official Journal of the European Union* L 342(60), 1-151. https://ec.europa.eu/health/sites/health/files/endocrine_disruptors/docs/cosmetic_1223_2009_regulation_en.pdf.

European Commission (2011a). Regulation (EU) no 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC. *Official Journal of the European Union* L 88(6). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011R0305&from=EN.

European Commission (2011b). Commission Recommendation of 18 October 2011 on the definition of nanomaterial (text with EEA relevance) (2011/696/EU). *Official Journal of the European Union* L 275(38), 1–3. http://ec.europa.eu/health/scientific_committees/emerging/docs/.

European Commission (2011c). Regulation (EU) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the provision of food information to consumers, amending Regulations (EC) No 1924/2006 and (EC) No 1925/2006 of the European Parliament and of the Council, and repealing Commission Directive 87/250/EEC, Council Directive 90/496/EEC, Commission Directive 1999/10/EC, Directive 2000/13/EC of the European Parliament and of the Council, Commission Directives 2002/67/EC and 2008/5/EC and Commission Regulation (EC) No 608/2004. *Official Journal of the European Union* L 304(18), 1-46. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011R1169&from=EN.

European Commission (2012a). Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE). Text with EEA relevance. *Official Journal of the European Union* L 197, 38-71. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0019&from=EN.

European Commission (2012b). Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products. *Official Journal of the European Union* L 167(2), 1-123. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0528&from=EN.

European Commission (2016a). *Defining Criteria for Identifying Endocrine Disruptors in the Context of the Implementation of the Plant Protection Products Regulation and Biocidal Products Regulation*. https://ec.europa.eu/health/sites/health/files/endocrine_disruptors/docs/2016_impact_assessment_en.pdf.

European Commission (2016b). Which substances are of concern? http://ec.europa.eu/environment/chemicals/endocrine/strategy/substances_en.htm. Accessed 29 May 2018.

European Commission (2017a). Directive (EU) 2017/2102 of the European Parliament and of the Council of 15 November 2017 amending Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment Text with EEA relevance. *Official Journal of the European Union* L 305, 8-11. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2017:305:FULL&from=EN.

European Commission (2017b). Commission Regulation (EU) 2017/1000 of 13 June 2017 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards perfluorooctanoic acid (PFOA), its salts and PFOA-related substances. *Official Journal of the European Union* L 150(14). https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32017R1000&from=EN.

European Commission (2017c). Public consultation on amendments of the annexes to REACH for registration of nanomaterials. https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2017-4925011_en. Accessed 23 November 2017.

European Commission (2017d). Commission Delegated Regulation (EU) 2017/2100 of 4 September 2017 setting out scientific criteria for the determination of endocrine-disrupting properties pursuant to Regulation (EU) No 528/2012 of the European Parliament and Council. *Official Journal of the European Union* L 301(1). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R2100&from=EN.

European Commission (2018). Commission Regulation (EU) 2018/605 of 19 April 2018 amending Annex II to Regulation (EC) No 1107/2009 by setting out scientific criteria for the determination of endocrine disrupting properties. *Official Journal of the European Union* L 101, 33-36. https://doi.org/10.2903/j.efsa.2013.3132.

European Commission (n.d.). Process to set scientific criteria to identify endocrine disruptors. https://ec.europa.eu/health/endocrine_disruptors/process_en. Accessed 14 August 2018.

European Environment Agency (2012). *The Impacts of Endocrine Disrupters on Wildlife, People and their Environments: the Weybridge+15 (1996-2011) Report*. Copenhagen. https://www.eea.europa.eu/publications/the-impacts-of-endocrine-disrupters.

Evens, A., Hryhorczuk, D., Lanphear, B.P., Rankin, K.M., Lewis, D.A., Forst, L. and Rosenberg, D. (2015). The impact of low-level lead toxicity on school performance among children in the Chicago public schools: a population-based retrospective cohort study. *Environmental Health* 14(21), 1-9. https://doi.org/10.1186/s12940-015-0008-9.

Fan, L., Niu, H., Yang, X., Qin, W., Bento, C.P.M., Ritsema, C.J. and Geissen, V. (2015). Factors affecting farmers' behaviour in pesticide use: Insights from a field study in northern China. *Science of the Total Environment* 537, 360-368. https://doi.org/10.1016/j.scitotenv.2015.07.150.

Fantke, P., Ernstoff, A.S., Huang, L., Csiszar, S.A. and Jolliet, O. (2016). Coupled near-field and far-field exposure assessment framework for chemicals in consumer products. *Environment International* 94, 508-518. https://doi.org/10.1016/j.envint.2016.06.010.

Fewtrell, L., Kaufmann, R. and Prüss-Üstün, A. (2003). *Lead: Assessing the Environmental Burden of Disease at National and Local Levels*. Geneva: World Health Organization. http://www.who.int/quantifying_ehimpacts/publications/en/leadebd2.pdf.

Fleischli, M.A., Franson, J.C., Thomas, N.J., Finley, D.L. and Riley, W. (2004). Avian mortality events in the United States caused by anticholinesterase pesticides: a retrospective summary of National Wildlife Health Center records from 1980 to 2000. *Archives of Environmental Contamination and Toxicology* 46(4), 542-550. http://www.ncbi.nlm.nih.gov/pubmed/15253053.

Flores-Valverde, A.M., Horwood, J. and Hill, E.M. (2010). Disruption of the steroid metabolome in fish caused by exposure to the environmental estrogen 17α-ethinylestradiol. *Environmental Science & Technology* 44(9), 3552-3558. https://doi.org/10.1021/es9039049.

Food and Agriculture Organization of the United Nations (2016). *Addressing Highly Hazardous Pesticides in Mozambique*. http://www.fao.org/3/a-i5360e.pdf.

Food and Agriculture Organization of the United Nations (2018a). *Pesticide Registration Toolkit.* http://www.fao.org/pesticide-registration-toolkit/en/.

Food and Agriculture Organization of the United Nations (2018b). AGP - Integrated Pest Management. http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/ipm/en/. Accessed 12 June 2018.

Food and Agriculture Organization of the United Nations and World Health Organization (2007). *1st FAO/WHO Joint Meeting on Pesticide Management and 3rd Session of the FAO Panel of Experts on Pesticide Management*. Rome: Food and Agriculture Organization of the United Nations and The World Health Organisation. http://www.who.int/whopes/recommendations/First_FAO_WHO_jmps07.pdf.

Food and Agriculture Organization of the United Nations and World Health Organization (2010). *4th FAO/WHO Joint Meeting on Pesticide Management and 6th Session of the FAO Panel of Experts on Pesticide Management*. http://www.who.int/whopes/recommendations/Fourth_FAO_WHO_jmps.pdf.

Food and Agriculture Organization of the United Nations and World Health Organization (2014a). *8th FAO/WHO Joint Meeting on Pesticide Management and 10th Session of The FAO Panel of Experts on Pesticide Management*. http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/8th_JMPM_2014_Report_22Dec14.pdf.

Food and Agriculture Organization of the United Nations and World Health Organization (2014b). *International Code of Conduct on Pesticide Management*. http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/CODE_2014Sep_ENG.pdf.

Food and Agriculture Organization of the United Nations and World Health Organization (2016). *International Code of Conduct on Pesticide Management: Guidelines on Highly Hazardous Pesticides*. http://apps.who.int/iris/bitstream/handle/10665/205561/9789241510417_eng.pdf?sequence=1&isAllowed=y.

Food and Agriculture Organization of the United Nations and World Health Organization (2017). *Report of the 10th FAO/WHO Joint Meeting on Pesticide Management*. http://www.who.int/about/licensing/copyright_form/en/index.html.

Fowler, B.A. (2017). Current E-Waste Data Gaps and Future Research Directions. In *Electronic Waste: Toxicology and Public Health Issues*. London: Elsevier 77-81. https://doi.org/10.1016/B978-0-12-803083-7.00007-X.

Fu, J., Zhang, A., Wang, T., Qu, G., Shao, J., Yuan, B., Wang, Y. and Jiang, G. (2013). Influence of e-waste dismantling and its regulations: temporal trend, spatial distribution of heavy metals in rice grains, and Its potential health risk. *Environmental Science & Technology* 47(13), 7437-7445. https://doi.org/10.1021/es304903b.

Fujimori, T., Takigami, H., Agusa, T., Eguchi, A., Bekki, K., Yoshida, A., Terazono, A. and Ballesteros, F.C. (2012). Impact of metals in surface matrices from formal and informal electronic-waste recycling around Metro Manila, the Philippines, and intra-Asian comparison. *Journal of Hazardous Materials* 221-222, 139-146. https://doi.org/10.1016/J.JHAZMAT.2012.04.019.

Galloway, T. and Handy, R. (2003). Immunotoxicity of organophosphorous pesticides. *Ecotoxicology* 12(1-4), 345-363. http://www.ncbi.nlm.nih.gov/pubmed/12739880.

Galloway, T.S. and Depledge, M.H. (2001). Immunotoxicity in invertebrates: measurement and ecotoxicological relevance. *Ecotoxicology* 10(1), 5-23. http://www.ncbi.nlm.nih.gov/pubmed/11227817.

Geeraerts, K., Illes, A. and Schweizer, J.-P. (2015). *Illegal Shipment of E-Waste from the EU: A Case Study on Illegal E-Waste Export from the EU to China. A Study Compiled as Part of the EFFACE Project*. London: Institute for European Environmental Policy. https://efface.eu/sites/default/files/EFFACE_Illegal%20shipment%20of%20e%20waste%20from%20the%20EU.pdf.

German Environment Agency (2014). *Biocides: Proposal for a Concerted European Approach Towards a Sustainable Use*. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/biocides_0.pdf.

German Environment Agency (2017). First OECD test guideline on the investigation of nanomaterials, 11 October. https://www.umweltbundesamt.de/en/topics/first-oecd-test-guideline-on-the-investigation-of. Accessed 13 June 2018.

Giulivo, M., Lopez de Alda, M., Capri, E. and Barceló, D. (2016). Human exposure to endocrine disrupting compounds: their role in reproductive systems, metabolic syndrome and breast cancer. A review. *Environmental Research* 151, 251-264. https://doi.org/10.1016/J.ENVRES.2016.07.011.

Goldenman, G., Holland, M., Lietzmann, J. and Meura, L. (2017). *Study for the Strategy for a Non-Toxic Environment of the 7th Environment Action Programme Final Report*. Brussels: European Commission DG Environment. https://doi.org/10.2779/025.

Gomis, M.I., Vestergren, R., Borg, D. and Cousins, I.T. (2018). Comparing the toxic potency *in vivo* of long-chain perfluoroalkyl acids and fluorinated alternatives. *Environment International* 113, 1-9. https://doi.org/10.1016/j.envint.2018.01.011.

Gore, A.C., Chappell, V.A., Fenton, S.E., Flaws, J.A., Nadal, A., Prins, G.S., Toppari, J. and Zoeller, R.T. (2015). EDC-2: The Endocrine Society's second scientific statement on endocrine-disrupting chemicals. *Endocrine Reviews* 36(6), E1-E150. http://dx.doi.org/10.1210/er.2015-1010.

Gore-Tex (2018). Responsible usage of fluoromaterials. https://www.gore-tex.com/pfcgoal. Accessed 13 June 2018.

Gottesfeld, P. (2015). Time to ban lead in industrial paints and coatings. *Frontiers in Public Health* 3(144), 1-4. https://doi.org/10.3389/fpubh.2015.00144.

Government of Canada (2017a). Fall 2016 amendments to the Prohibition of Certain Toxic Substances Regulations, 7 July. https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/fall-2016-amendments-prohibition-toxic-substances.html. Accessed 13 June 2018.

Government of Canada (2017b). Regulatory Cooperation Council (RCC), 12 April. http://science.gc.ca/eic/site/063.nsf/eng/h_97378.html. Accessed 18 February 2018

Grant, K., Goldizen, F.C., Sly, P.D., Brune, M.-N., Neira, M., van den Berg, M. and Norman, R.E. (2013). Health consequences of exposure to e-waste: a systematic review. *Lancet Global Health* 1(6), 350-361. https://doi.org/10.1016/S2214-109X(13)70101-3.

Green, R.E., Newton, I., Shultz, S., Cunningham, A.A., Gilbert, M., Pain, D.J. and Prakash, V. (2004). Diclofenac poisoning as a cause of vulture population declines across the Indian subcontinent. *Journal of Applied Ecology* 41(5), 793-800. https://doi.org/10.1111/j.0021-8901.2004.00954.x.

Gunnarsson, B. and Wennmalm, Å. (2008). Mitigation of the pharmaceutical outlet into the environment – experiences from Sweden. In *Pharmaceuticals in the Environment: Sources, Fate, Effects and Risks.* 3rd edn. Kümmerer, K. (ed.). Freiburg: Springer-Verlag. Chapter 30, 475-487. https://link.springer.com/content/pdf/10.1007%2F978-3-540-74664-5.pdf.

Guo, J., Sinclair, C.J., Selby, K. and Boxall, A.B.A. (2016). Toxicological and ecotoxicological risk-based prioritization of pharmaceuticals in the natural environment. *Environmental Toxicology and Chemistry* 35(6), 1550-1559. https://doi.org/10.1002/etc.3319.

Gustafsson, L.L., Wettermark, B., Godman, B., Andersén-Karlsson, E., Bergman, U., Hasselström, J., Hensjö, L.-O., Hjemdahl, P., Jägre, I., Julander, M., Ringertz, B., Schmidt, D., Sjöberg, S., Sjöqvist, F., Stiller, C.-O., Törnqvist, E., Tryselius, R., Vitols, S. and von Bahr, C. (2011). The 'wise list' – a comprehensive concept to select, communicate and achieve adherence to recommendations of essential drugs in ambulatory care in Stockholm. *Basic & Clinical Pharmacology & Toxicology* 108(4), 224-233. https://doi.org/10.1111/j.1742-7843.2011.00682.x.

Gwinn, M.R. and Vallyathan, V. (2006). Nanoparticles: health effects-pros and cons. *Environmental health perspectives* 114(12), 1818-1825. https://doi.org/10.1289/EHP.8871.

Haiß, A., Jordan, A., Westphal, J., Logunova, E., Gathergood, N. and Kümmer, K. (2016). On the way to greener ionic liquids: identification of a fully mineralizable phenylalanine-based ionic liquid. *Green Chemistry* 18, 4361-4373. http://doi.org/10.1039/C6GC00417B.

Hamlin, H.J. and Guillette, L.J. (2010). Birth defects in wildlife: the role of environmental contaminants as inducers of reproductive and developmental dysfunction. *Systems Biology in Reproductive Medicine* 56(2), 113-121. https://doi.org/10.3109/19396360903244598.

Hansen, S.F. (2017). React now regarding nanomaterial regulation. *Nature Nanotechnology* 12(8), 714-716. https://doi.org/10.1038/nnano.2017.163.

Hansen, S.F., Heggelund, L.R., Revilla Besora, P., Mackevica, A., Boldrin, A. and Baun, A. (2016). Nanoproducts – what is actually available to European consumers? *Environmental Science: Nano* 3(1), 169-180. https://doi.org/10.1039/C5EN00182J.

Hartemann, P., Hoet, P., Proykova, A., Fernandes, T., Baun, A., De Jong, W., Filser, J., Hensten, A., Kneuer, C., Maillard, J.-Y., Norppa, H., Scheringer, M. and Wijnhoven, S. (2015). Nanosilver: safety, health and environmental effects and role in antimicrobial resistance. *Materials Today* 18(3), 122-123. https://doi.org/10.1016/J.MATTOD.2015.02.014.

Hayes, T.B., Khoury, V., Narayan, A., Nazir, M., Park, A., Brown, T., Adame, L., Chan, E., Buchholz, D., Stueve, T. and Gallipeau, S. (2010). Atrazine induces complete feminization and chemical castration in male African clawed frogs (*Xenopus laevis*). *Proceedings of the National Academy of Sciences* 107(10), 4612-4617. https://doi.org/10.1073/pnas.0909519107.

Heacock, M., Kelly, C.B., Asante, K.A., Birnbaum, L.S., Bergman, Å.L., Bruné, M.-N., Buka, I., Carpenter, D.O., Chen, A., Huo, X., Kamel, M., Landrigan, P.J., Magalini, F., Diaz-Barriga, F., Neira, M., Omar, M., Pascale, A., Ruchirawat, M., Sly, L., Sly, P.D., Van den Berg, M. and Suk, W.A. (2016). E-waste and harm to vulnerable populations: a growing global problem. *Environmental Health Perspectives* 124(5), 550-555. https://doi.org/10.1289/ehp.1509699.

Health Canada (2013a). *Final Human Health State of the Science Report on Lead.* https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/contaminants/dhhssrl-rpecscepsh/dhhssrl-rpecscepsh-eng.pdf.

Health Canada (2013b). *Risk Management Strategy for Lead.* https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/contaminants/prms_lead-psgr_plomb/prms_lead-psgr_plomb-eng.pdf.

Heberer, T. and Feldmann, D. (2005). Contribution of effluents from hospitals and private households to the total loads of diclofenac and carbamazepine in municipal sewage effluents – modeling versus measurements. *Journal of Hazardous Materials* 122(3), 211-218. https://doi.org/10.1016/J.JHAZMAT.2005.03.007.

Hollender, J., Zimmermann, S.G., Koepke, S., Krauss, M., McArdell, C.S., Ort, C., Singer, H., von Gunten, U. and Siegrist, H. (2009). Elimination of organic micropollutants in a municipal wastewater treatment plant upgraded with a full-scale post-ozonation followed by sand filtration. *Environmental Science & Technology* 43(20), 7862-7869. https://doi.org/10.1021/es9014629.

Holmquist, H., Schellenberger, S., van der Veen, I., Peters, G.M., Leonards, P.E.G. and Cousins, I.T. (2016). Properties, performance and associated hazards of state-of-the-art durable water repellent (DWR) chemistry for textile finishing. *Environment International* 91, 251-264. https://doi.org/10.1016/J.ENVINT.2016.02.035.

Huang, S., Wang, L., Liu, L., Fu, Q. and Zhu, D. (2014). Nonchemical pest control in China rice: a review. *Agronomy for Sustainable Development* 34(2), 275-291. https://doi.org/10.1007/s13593-013-0199-9.

Hughes, D., Kibbey, J. and Rudgeway, R. (2014). Emerging vertical partnerships for scale in impact measurement: the case of the Higg Index, 23 June. *Sustainable Brands.* https://www.slideshare.net/sustainablebrands/emerging-vertical-partnerships-for-scale-in-impact-measurement-the-case-of-the-higg-index. Accessed 12 June 2018.

IKEA (2017). *Vanliga Frågor Och Svar Perfluorerade Ämnen*. Inter IKEA Systems B.V. https://www.ikea.com/ms/sv_SE/pdf/sustainability/kemikalier/FAQ_Perfluorerade_amnen.pdf.

International Federation of Pharmaceutical Manufacturers & Associations (2017). *The Pharmaceutical Industry and Global Health – Facts and Figures 2017*. https://www.ifpma.org/wp-content/uploads/2017/02/IFPMA-Facts-And-Figures-2017.pdf.

International Organization for Standardization (2017). ISO/TR 18401:2017(en), Nanotechnologies — Plain language explanation of selected terms from the ISO/IEC 80004 series. https://www.iso.org/obp/ui/#iso:std:iso:tr:18401:ed-1:v1:en. Accessed 13 June 2018.

International Paint and Printing Ink Council (2015). *Module D Industry Perspective on the Elimination of Lead Paint*. http://web.unep.org/sites/all/themes/noleadpaint/docs/Module%20D%20Industry%20Perspective%20FINAL.pdf.

International POPs Elimination Network (2016). *Global Lead Paint Elimination Report*. http://ipen.org/sites/default/files/documents/IPEN-global-lead-report-final-Oct-2016-en.pdf.

International POPs Elimination Network (2017). *Lead in Solvent-Based Paints for Home Use Global Report*. http://ipen.org/sites/default/files/documents/ipen-global-lead-report-2017-v1_2-en.pdf.

Interstate Technology and Regulatory Council (2017). PFAS fact sheets – PFAS per- and polyfluoroalkyl substances. https://pfas-1.itrcweb.org/fact-sheets/. Accessed 13 August 2018.

Jain, A., Ranjan, S., Dasgupta, N. and Ramalingam, C. (2018). Nanomaterials in food and agriculture: an overview on their safety concerns and regulatory issues. *Critical Reviews in Food Science and Nutrition* 58(2), 297-317. https://doi.org/10.1080/10408398.2016.1160363.

Japan External Trade Organization (2011). *Guidebook for Export to Japan 2011 (Cosmetics)*. http://www.acma.us/content/pdf/guidebook_cosmetics.pdf.

Joint Article Management Promotion-consortium (2018). *Guidelines for the Management of Chemicals in Products (CiP): Deliberation of Collaboration Committee of Guidelines for Chemicals in Products*. 4th edn. https://chemsherpa.net/english/docs/guidelines.

Jones, W., Gibb, A., Goodier, C. and Bust, P. (2017). Managing the unknown – addressing the potential health risks of nanomaterials in the built environment. *Construction Management and Economics* 35(3), 122-136. https://doi.org/10.1080/01446193.2016.1241413.

Kabir, E.R., Rahman, M.S. and Rahman, I. (2015). A review on endocrine disruptors and their possible impacts on human health. *Environmental Toxicology and Pharmacology* 40(1), 241-258. https://doi.org/10.1016/J.ETAP.2015.06.009.

Kah, M., Beulke, S., Tiede, K. and Hofmann, T. (2013). Nanopesticides: state of knowledge, environmental fate, and exposure modeling. *Critical Reviews in Environmental Science and Technology* 43(16), 1823-1867. https://doi.org/10.1080/10643389.2012.671750.

Karim, E., Munir, A.B., Reza, A.W., Muhammad-Sukki, F., Mohd Yasin, S.H., Abu-Bakar, S.H. and Abdul Rahim, R. (2015). Too enthusiastic to care for safety: present status and recent developments of nanosafety in ASEAN countries. *Technological Forecasting and Social Change* 92, 168-181. https://doi.org/10.1016/J.TECHFORE.2014.07.003.

Karunaratne, G.P. (2015). Environmental and Health Impacts of Nanotechnology: Need for a Precautionary Approach. *Journal of Chemical Engineering Research Studies* 2(1), 1-3. https://www.researchgate.net/publication/271966445.

Keller, A.A., McFerran, S., Lazareva, A. and Suh, S. (2013). Global life cycle releases of engineered nanomaterials. *Journal of Nanoparticle Research* 15(6), 1692-1694. https://doi.org/10.1007/s11051-013-1692-4.

Kessler, R. (2014). Lead-based decorative paints: where are they still sold – and why? *Environmental Health Perspectives* 122(4), A96-A103. https://doi.org/10.1289/EHP.122-A96.

Khan, M., Mahmood, H.Z. and Damalas, C.A. (2015). Pesticide use and risk perceptions among farmers in the cotton belt of Punjab, Pakistan. *Crop Protection* 67, 184-190. https://doi.org/10.1016/J.CROPRO.2014.10.013.

Khot, L.R., Sankaran, S., Maja, J.M., Ehsani, R. and Schuster, E.W. (2012). Applications of nanomaterials in agricultural production and crop protection: A review. *Crop Protection* 35, 64-70. https://doi.org/10.1016/J.CROPRO.2012.01.007.

Kim, I., Kim, H.J., Lim, S.Y. and Kongyoo, J. (2012). Leukemia and Non-Hodgkin lymphoma in semiconductor industry workers in Korea. *International Journal of Occupational and Environmental Health* 18(2), 147-153. https://doi.org/10.1179/1077352512Z.00000000019.

Kim, K.-H., Kabir, E. and Jahan, S.A. (2017). Exposure to pesticides and the associated human health effects. *Science of the Total Environment* 575, 525-535. https://doi.org/10.1016/j.scitotenv.2016.09.009.

Klaine, S.J., Alvarez, P.J.J., Batley, G.E., Fernandes, T.F., Handy, R.D., Lyon, D.Y., Mahendra, S., McLaughlin, M.J. and Lead, J.R. (2008). Nanomaterials in the environment: behavior, fate, bioavailability, and effects. *Environmental Toxicology and Chemistry* 27(9), 1825. https://doi.org/10.1897/08-090.1.

Klatte, S., Schaefer, H.-C. and Hempel, M. (2017). Pharmaceuticals in the environment – a short review on options to minimize the exposure of humans, animals and ecosystems. *Sustainable Chemistry and Pharmacy* 5, 61-66. https://doi.org/10.1016/J.SCP.2016.07.001.

Klees, M., Hombrecher, K. and Gladtke, D. (2017). Polychlorinated biphenyls in the surrounding of an e-waste recycling facility in North-Rhine Westphalia: levels in plants and dusts, spatial distribution, homologue pattern and source identification using the combination of plants and wind direction data. *Science of the Total Environment* 603-604, 606-615. https://doi.org/10.1016/j.scitotenv.2017.06.079.

Knipe, D.W., Chang, S.-S., Dawson, A., Eddleston, M., Konradsen, F., Metcalfe, C. and Gunnell, D. (2017). Suicide prevention through means restriction: impact of the 2008-2011 pesticide restrictions on suicide in Sri Lanka. *PLoS ONE* 12(4), 1-12. https://doi.org/10.1371/journal.pone.0172893.

Kogg, B. and Thidell, Å. (2010). *Chemicals in Products an Overview of Systems for Providing Information Regarding Chemicals in Products and of Stakeholders' Needs for Such Information*. Lund: United Nations Environment Programme. http://www.saicm.org/Portals/12/Documents/EPI/Guidance%20for%20Stakeholder%20in%20Exchanging%20CiP%20Information_October2015.pdf.

Koh, D., Chan, G. and Yap, E. (2004). World at work: the electronics industry. *Occupational and Environmental Medicine* 61(2), 180-183. https://doi.org/10.1136/OEM.2002.001073.

Kohler, H.-R. and Triebskorn, R. (2013). Wildlife ecotoxicology of pesticides: can we track effects to the population level and beyond? *Science* 341(6147), 759-765. https://doi.org/10.1126/science.1237591.

Kookana, R.S., Boxall, A.B.A., Reeves, P.T., Ashauer, R., Beulke, S., Chaudhry, Q., Cornelis, G., Fernandes, T.F., Gan, J., Kah, M., Lynch, I., Ranville, J., Sinclair, C., Spurgeon, D., Tiede, K. and Van den Brink, P.J. (2014). Nanopesticides: guiding principles for regulatory evaluation of environmental risks. *Journal of Agricultural and Food Chemistry* 62(19), 4227-4240. https://doi.org/10.1021/jf500232f.

Kramer, V.J., Etterson, M.A., Hecker, M., Murphy, C.A., Roesijadi, G., Spade, D.J., Spromberg, J.A., Wang, M. and Ankley, G.T. (2011). Adverse outcome pathways and ecological risk assessment: bridging to population-level effects. *Environmental Toxicology and Chemistry* 30(1), 64-76. https://doi.org/10.1002/etc.375.

Krug, H.F. (2014). Nanosafety research – are we on the right track? *Angewandte Chemie International Edition* 53(46), 12304-12319. https://doi.org/10.1002/anie.201403367.

Kuang, J., Abdallah, M.A.-E. and Harrad, S. (2018). Brominated flame retardants in black plastic kitchen utensils: concentrations and human exposure implications. *Science of the Total Environment* 610-611, 1138-1146. https://doi.org/10.1016/J.SCITOTENV.2017.08.173.

Kümmerer, K. (ed.) (2004). *Pharmaceuticals in the Environment: Sources, Fate, Effects and Risks*. 2nd edition. Berlin: Springer. https://doi.org/10.1007/978-3-662-09259-0.

Kümmerer, K. (2009). The presence of pharmaceuticals in the environment due to human use – present knowledge and future challenges. *Journal of Environmental Management* 90(8), 2354-2366. https://doi.org/10.1016/j.jenvman.2009.01.023.

Kümmerer, K., Dionysiou, D.D., Olsson, O. and Fatta-Kassinos, D. (2018). A path to clean water. *Science* 361(6399), 222-224. http://doi.org/10.1126/science.aau2405.

Kümmerer, K., Dionysiou, D.D., Olsson, O. and Fatta-Kassinos, D. (2019). Reducing aquatic micropollutants – increasing the focus on input prevention and integrated emission management. *Science of The Total Environment* 652, 836-850. https://doi.org/10.1016/j.scitotenv.2018.10.219.

Kümmerer, K. and Hempel, M. (eds.) (2010). *Green and Sustainable Pharmacy*. Berlin: Springer. https://doi.org/10.1007/978-3-642-05199-9.

Küster, A. and Adler, N. (2014). Pharmaceuticals in the environment: scientific evidence of risks and its regulation. *Philosophical Transactions of the Royal Society of London. Series B, Biological sciences* 369(1656), 1-8. https://doi.org/10.1098/rstb.2013.0587.

Lagarde, F., Beausoleil, C., Belcher, S.M., Belzunces, L.P., Emond, C., Guerbet, M. and Rousselle, C. (2015). Non-monotonic dose-response relationships and endocrine disruptors: a qualitative method of assessment. *Environmental Health* 14(1), 1-13. https://doi.org/10.1186/1476-069X-14-13.

Land, M., de Wit, C.A., Bignert, A., Cousins, I.T., Herzke, D., Johansson, J.H and Martin, J.W. (2018). What is the effect of phasing out long-chain per- and polyfluoroalkyl substances on the concentrations of perfluoroalkyl acids and their precursors in the environment? A systematic review. *Environmental Evidence* 7(4), 1-32. https://doi.org/10.1186/s13750-017-0114-y.

Lange, A., Paull, G.C., Coe, T.S., Katsu, Y., Urushitani, H., Iguchi, T. and Tyler, C.R. (2009). Sexual reprogramming and estrogenic sensitization in wild fish exposed to ethinylestradiol. *Environmental Science & Technology* 43(4), 1219-1225. https://doi.org/10.1021/es802661p.

Lapworth, D.J., Baran, N., Stuart, M.E. and Ward, R.S. (2012). Emerging organic contaminants in groundwater: a review of sources, fate and occurrence. *Environmental Pollution* 163, 287-303. https://doi.org/10.1016/J.ENVPOL.2011.12.034.

Lechenet, M., Dessaint, F., Py, G., Makowski, D. and Munier-Jolain, N. (2017). Reducing pesticide use while preserving crop productivity and profitability on arable farms. *Nature Plants* 3(17008), 1-6. https://doi.org/10.1038/nplants.2017.8.

Lowry, G.V., Gregory, K.B., Apte, S.C. and Lead, J.R. (2012). Transformations of nanomaterials in the environment. *Environmental Science & Technology* 46(13), 6893-6899. https://doi.org/10.1021/es300839e.

Lübbert, C., Baars, C., Dayakar, A., Lippmann, N., Rodloff, A.C., Kinzig, M. and Sörgel, F. (2017). Environmental pollution with antimicrobial agents from bulk drug manufacturing industries in Hyderabad, South India, is associated with dissemination of extended-spectrum beta-lactamase and carbapenemase-producing pathogens. *Infection* 45(4), 479-491. https://doi.org/10.1007/s15010-017-1007-2.

Lubick, N. (2008). Opening the “green pharmacy”. *Environmental Science & Technology* 42(23), 8620-8621. https://doi.org/10.1021/es802555w.

Lynch, I., Feitshans, I.L. and Kendall, M. (2015). ‘Bio-nano interactions: new tools, insights and impacts’: summary of the Royal Society discussion meeting. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 370(1661), 1-11. https://doi.org/10.1098/rstb.2014.0162.

Madikizela, L.M., Tavengwa, N.T. and Chimuka, L. (2017). Status of pharmaceuticals in African water bodies: occurrence, removal and analytical methods. *Journal of Environmental Management* 193, 211-220. https://doi.org/10.1016/J.JENVMAN.2017.02.022.

Mancini, F., van der Valk, H., Cassam, K. and Davis, M. (2016). *Reducing Risks of Highly Hazardous Pesticides (HHPs) in Mozambique*. Food and Agriculture Organization of United Nations. https://slideplayer.com/slide/10700846/.

Mañosa, S., Mateo, R. and Guitart, R. (2001). A review of the effects of agricultural and industrial contamination on the Ebro delta biota and wildlife. *Environmental monitoring and assessment* 71(2), 187-205. http://www.ncbi.nlm.nih.gov/pubmed/11686200.

Manuweera, G., Eddleston, M., Egodage, S. and Buckley, N.A. (2008). Do targeted bans of insecticides to prevent deaths from self-poisoning result in reduced agricultural output? *Environmental Health Perspectives* 116(4), 492-495. https://doi.org/10.1289/ehp.11029.

Maynard, A.D. and Aitken, R.J. (2016). ‘Safe handling of nanotechnology’ ten years on. *Nature Nanotechnology* 11, 998. https://doi.org/10.1038/nnano.2016.270.

Melvin, S.D. and Leusch, F.D.L. (2016). Removal of trace organic contaminants from domestic wastewater: a meta-analysis comparison of sewage treatment technologies. *Environment International* 92-93, 183-188. https://doi.org/10.1016/J.ENVINT.2016.03.031.

Menard, S., Guzylack-Piriou, L., Leveque, M., Braniste, V., Lencina, C., Naturel, M., Moussa, L., Sekkal, S., Harkat, C., Gaultier, E., Theodorou, V. and Houdeau, E. (2014). Food intolerance at adulthood after perinatal exposure to the endocrine disruptor bisphenol A. *The Federation of American Societies for Experimental Biology Journal* 28(11), 4893-4900. https://doi.org/10.1096/fj.14-255380.

Merhi, M., Raynal, H., Cahuzac, E., Vinson, F., Cravedi, J.P. and Gamet-Payrastre, L. (2007). Occupational exposure to pesticides and risk of hematopoietic cancers: meta-analysis of case–control studies. *Cancer Causes & Control* 18(10), 1209-1226. https://doi.org/10.1007/s10552-007-9061-1.

Miller, G.Z., Tighe, M.E., Peaslee, G.F., Peña, K. and Gearhart, J. (2016). Toys, décor, and more: evidence of hazardous electronic waste recycled into new consumer products. *Journal of Environmental Protection* 07(03), 341-350. https://doi.org/10.4236/jep.2016.73030.

Ministry of Environment Forest and Climate Change of India (2016). *Government of India Ministry of Environment, Forest and Climate Change E-waste Management and Handling Rules Notification*. http://www.moef.gov.in/sites/default/files/EWM%20Rules%202016%20english%2023.03.2016.pdf.

Ministry of the Environment of Japan (2010). *Further Actions to Endocrine Disrupting Effects of Chemical Substances - EXTEND 2010*. https://www.env.go.jp/en/chemi/ed/extend2010_full.pdf.

Mishima, T. (2017). Regulations on and management of chemical substances in products. *Sei Technical Review* 85(5), 5-9. http://global-sei.com/technology/tr/bn85/pdf/85-01.pdf.

Mmereki, D., Baldwin, A., Hong, L. and Li B. (2016). The management of hazardous waste in developing countries. In *Management of Hazardous Wastes*. Saleh, H.E.-D.M. and Rahman, R.A. (eds.). London: Intech. Chapter 3. 39-51 http://doi.org/10.5772/63055.

Montaño, M.D., Lowry, G.V, Von Der Kammer, F., Blue, J. and Ranville, J.F. (2014). Current status and future direction for examining engineered nanoparticles in natural systems. *Environmental Chemistry* 11, 351-366. https://doi.org/10.1071/EN14037.

Monteiro, S.C. and Boxall, A.B.A. (2010). Occurrence and fate of human pharmaceuticals in the environment BT – reviews of environmental contamination and toxicology. In *Reviews of Environmental Contamination and Toxicology.* Whitacre, D.M. (ed.). New York: Springer. 53-154. https://doi.org/10.1007/978-1-4419-1157-5_2.

Mostafalou, S. and Abdollahi, M. (2017). Pesticides: an update of human exposure and toxicity. *Archives of Toxicology* 91(2), 549-599. https://doi.org/10.1007/s00204-016-1849-x.

National Research Council of the National Academies (2014). *Review of the Environmental Protection Agency's State-of-the-Science Evaluation of Nonmonotonic Dose-Response Relationships as they Apply to Endocrine Disruptors*. Washington, D.C.: National Academies Press. https://www.nap.edu/catalog/18608/review-of-the-environmental-protection-agencys-state-of-the-science-evaluation-of-nonmonotonic-dose-response-relationships-as-they-apply-to-endocrine-disruptors.

Neumann, M. and Schliebner, I. (2017). *Protecting the Sources of our Drinking Water from Mobile Chemicals: A Revised Proposal for Implementing Criteria and an Assessment Procedure to Identify Persistent, Mobile and Toxic (PMT) and Very Persistent, Very Mobile (vPvM) Substances Registered Under REACH*. 2nd edn. Dessau-Roßlau: German Environment Agency. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/171027_uba_pos_pmt_substances_engl_2aufl_bf.pdf.

Nevin, R. (2007). Understanding international crime trends: the legacy of preschool lead exposure. *Environmental Research* 104(3), 315-336. https://doi.org/10.1016/j.envres.2007.02.008.

Nimpuno, N., McPherson, A. and Sadique, T. (2009). *Greening Consumer Electronics – Moving Away from Bromine and Chlorine*. Göteborg and Spring Brook: International Chemical Secretariat and Clean Production Action. https://www.cleanproduction.org/static/ee_images/uploads/resources/Greening_Consumer_Electronics.pdf.

Norwegian Environment Agency (2013). Forbyr PFOA i norske forbrukerprodukter. http://www.miljodirektoratet.no/no/Nyheter/Nyheter/Old-klif/2013/juni-2013/Forbyr-PFOA-i-norske-forbrukerprodukter/. Accessed 13 June 2018.

Nowack, B., Brouwer, C., Geertsma, R.E., Heugens, E.H.W., Ross, B.L., Toufektsian, M.-C., Wijnhoven, S.W.P. and Aitken, R.J. (2012). Analysis of the occupational, consumer and environmental exposure to engineered nanomaterials used in 10 technology sectors. *Nanotoxicology* 7(6), 1152-1156. https://doi.org/10.3109/17435390.2012.711863.

O'Connor, M.P., Zimmerman, J.B., Anastas, P.T. and Plata, D.L. (2016). A strategy for material supply chain sustainability: enabling a circular economy in the electronics industry through green engineering. *ACS Sustainable Chemistry & Engineering* 4(11), 5879-5888. https://doi.org/10.1021/acssuschemeng.6b01954.

Oaks, J.L., Gilbert, M., Virani, M.Z., Watson, R.T., Meteyer, C.U., Rideout, B.A., Shivaprasad, H.L., Ahmed, S., Iqbal Chaudhry, M.J., Arshad, M., Mahmood, S., Ali, A. and Ahmed Khan, A. (2004). Diclofenac residues as the cause of vulture population decline in Pakistan. *Nature* 427(6975), 630-633. https://doi.org/10.1038/nature02317.

Office of Environmental Health Hazard Assessment of California (2018). The Proposition 65 List. https://oehha.ca.gov/proposition-65/proposition-65-list. Accessed 12 June 2018.

Organisation for Economic Cooperation and Development (2013). *OECD/UNEP Global PFC Group, Synthesis Paper on Per- and Polyfluorinated Chemicals (PFCs)*. Paris: Environment, Health and Safety, Environment Directorate. https://www.oecd.org/env/ehs/risk-management/PFC_FINAL-Web.pdf.

Organisation for Economic Cooperation and Development (2015). *OECD/UNEP Risk Reduction Approaches for PFASS – A Cross-Country Analysis*. https://www.oecd.org/chemicalsafety/risk-management/Risk_Reduction_Approaches%20for%20PFASS.pdf.

Organisation for Economic Cooperation and Development (2017a). *Resource Compendium of PRTR Part 4: Summary of Techniques for Releases from Products*. *Series on Pollutant Release and Transfer Registers*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2017)2/ann&doclanguage=en.

Organisation for Economic Cooperation and Development (2017b). Test no. 318: dispersion stability of nanomaterials in simulated environmental media. In *OECD Guidelines for the Testing of Chemicals*. https://doi.org/10.1787/9789264284142-en.

Organisation for Economic Cooperation and Development (2017c). Recommendation of the council on the safety testing and assessment of manufactured nanomaterials. https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0400. Accessed 13 August 2018.

Organisation for Economic Cooperation and Development (2018a). *Best Practice Guidance to Identify Illegal Trade of Pesticides.* https://one.oecd.org/document/ENV/JM/MONO(2018)35/en/pdf.

Organisation for Economic Cooperation and Development (2018b). *Toward a New Comprehensive Global Database of Per- and Polyfluoroalkyl Substances (PFASs): Summary Report on Updating the OECD 2007 List Of per- and Polyfluoroalkyl Substances (PFASs).*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en.

Organisation for Economic Cooperation and Development (2018c). Test no. 412: subacute inhalation toxicity: 28-day study. In *OECD Guidelines for the Testing of Chemicals.* https://doi.org/10.1787/20745788.

Organisation for Economic Cooperation and Development (2018d). Test no. 413: subchronic inhalation toxicity: 90-day study. In *OECD Guidelines for the Testing of Chemicals.* https://doi.org/10.1787/9789264070806-en.

Organisation for Economic Cooperation and Development (2018e). OECD guidelines for the testing of chemicals. http://www.oecd.org/chemicalsafety/testing/oecdguidelinesforthetestingofchemicals.htm. Accessed 1 January 2019.

Organisation for Economic Cooperation and Development (2018f). OECD work related to endocrine disrupters. http://www.oecd.org/chemicalsafety/testing/oecdworkrelatedtoendocrinedisrupters.htm. Accessed 14 August 2018.

Organisation for Economic Cooperation and Development (2018g). *Revised Guidance Document 150 on Standardised Test Guidelines for Evaluating Chemicals for Endocrine Disruption.* https://doi.org/10.1787/9789264304741-en.

Ottinger, M.A. and Dean, K.M. (2011). Neuroendocrine impacts of endocrine-disrupting chemicals in birds: life stage and species sensitivities. *Journal of Toxicology and Environmental Health, Part B* 14(5–7), 413-422. https://doi.org/10.1080/10937404.2011.578560.

Persistent Organic Pollutants Review Committee (2016). *Consolidated Guidance on Alternatives to Perfluorooctane Sulfonic Acid (PFOS) and its Related Chemicals*. https://www.informea.org/sites/default/files/imported-documents/UNEP-POPS-POPRC.12-INF-15-Rev.1.English.pdf.

Pesticide Action Network (2016). *PAN International List of Highly Hazardous Pesticides*. http://www.pan-germany.org/download/PAN_HHP_List_161212_F.pdf.

Popp, J., Pető, K. and Nagy, J. (2013). Pesticide productivity and food security. A review. *Agronomy for Sustainable Development* 33(1), 243-255. https://doi.org/10.1007/s13593-012-0105-x.

Praetorius, A., Gundlach-Graham, A., Goldberg, E., Fabienke, W., Navratilova, J., Gondikas, A., Kaegi, R., Günther, D., Hofmann, T. and von der Kammer, F. (2017). Single-particle multi-element fingerprinting (spMEF) using inductively-coupled plasma time-of-flight mass spectrometry (ICP-TOFMS) to identify engineered nanoparticles against the elevated natural background in soils. *Environmental Science: Nano* 4(2), 307-314. https://doi.org/10.1039/C6EN00455E.

Premalatha, M., Abbasi, T., Abbasi, S.A. and Abbasi, S.A. (2014). The generation, impact, and management of e-waste: state of the art. *Critical Reviews in Environmental Science and Technology* 44(14), 1577-1678. https://doi.org/10.1080/10643389.2013.782171.

Prevedouros, K., Cousins, I.T., Buck, R.C. and Korzeniowski, S.H. (2006). Sources, fate and transport of perfluorocarboxylates. *Environmental Science & Technology* 40(1), 32-44. https://doi.org/10.1021/es0512475.

Public Eye (2017). UN experts fail to deliver assessment of Bayer and Syngenta compliance with the International Code of Conduct on Pesticide Management, 27 November. https://www.publiceye.ch/en/news/detail/un-experts-fail-to-deliver-assessment-of-bayer-and-syngenta-compliance-with-the-international-code-of-conduct-on-pesticide-management. Accessed 18 February 2019.

Puckowski, A., Mioduszewska, K., Łukaszewicz, P., Borecka, M., Caban, M., Maszkowska, J. and Stepnowski, P. (2016). Bioaccumulation and analytics of pharmaceutical residues in the environment: a review. *Journal of Pharmaceutical and Biomedical Analysis* 127, 232-255. https://doi.org/10.1016/J.JPBA.2016.02.049.

Rastogi, T., Leder, C and Kümmerer, K. (2015). Re-designing of existing pharmaceuticals for environmental biodegradability: a tiered approach with β-blocker propranolol as an example. *Environmental Science & Technology* 49(19), 11756-11763. http://doi.org/10.1021/acs.est.5b03051.

Reddy, P.P. (2016). Agro-ecological Pest Management. In *Sustainable Intensification of Crop Production*. Singapore: Springer. Chapter 18. 269-287. https://doi.org/10.1007/978-981-10-2702-4_18.

Reihlen, A. (2017). *Study for the Strategy for a Non-Toxic Environment of the 7th EAP Sub-Study B: Chemicals in Products and Non-Toxic Material Cycles*. Brussels: European Commission DG Environment. http://ec.europa.eu/environment/chemicals/non-toxic/pdf/Sub-study%20b%20articles%20non-toxic%20material%20cycles%20NTE%20final.pdf.

Rengam, S.V., Serrana, M.S., Quijano, I.I., Castillo, D. and Ravindran, D. (2018). *Of Rights and Poisons: Accountability of the Agrochemical Industry*. Penang: Pesticide Action Network Asia Pacific. http://files.panap.net/resources/Of-Rights-and-Poisons-Accountability-of-the-Agrochemical-Industry.pdf.

Research and Markets (2018). *Global Nanotechnology Market Outlook 2018-2024*. RNCOS E-Services Private Limited. https://www.researchandmarkets.com/reports/4536705/global-nanotechnology-market-outlook-2018-2024.

Rim, K.-T. (2017). Reproductive toxic chemicals at work and efforts to protect workers' health: a literature review. *Safety and Health at Work* 8(2), 143-150. https://doi.org/10.1016/J.SHAW.2017.04.003.

Ritscher, A., Wang, Z., Scheringer, M., Boucher, J.M., Ahrens, L., Berger, U., Bintein, S., Bopp, S.K., Borg, D., Buser, A.M., Cousins, I., DeWitt, J., Fletcher, T., Green, C., Herzke, D., Higgins, C., Huang, J., Hung, H., Knepper, T., Lau, C.S., Leinala, E., Lindstrom, A.B., Liu, J., Miller, M., Ohno, K., Perkola, N., Shi, Y., Småstuen Haug, L., Trier, X., Valsecchi, S., van der Jagt, K. and Vierke, L. (2018). Zürich Statement on Future Actions on Per- and Polyfluoroalkyl Substances (PFASs). *Environmental Health Perspectives*, 126(8), 084502 1-5. https://doi.org/10.1289/EHP4158.

Roos, V., Gunnarsson, L., Fick, J., Larsson, D.G.J. and Rudén, C. (2012). Prioritising pharmaceuticals for environmental risk assessment: towards adequate and feasible first-tier selection. *Science of the Total Environment* 421-422, 102-110. https://doi.org/10.1016/J.SCITOTENV.2012.01.039.

Ross, I., McDonough, J., Miles, J., Storch, P., Kochunarayanan, P.T., Kalve, E., Hurst, J., Dasgupta, S. and Burdick, J. (2018). A review of emerging technologies for remediation of PFASs. *Remediation Journal* 28(2), 101-126. https://doi.org/10.1002/rem.21553.

Rother, H.-A. (2016). Pesticide vendors in the informal sector. *New Solutions: A Journal of Environmental and Occupational Health Policy* 26(2), 241-252. https://doi.org/10.1177/1048291116651750.

Rother, H.-A. (2018). Pesticide labels: protecting liability or health? – unpacking 'misuse' of pesticides. *Current Opinion in Environmental Science & Health* 4, 10-15. https://doi.org/10.1016/j.coesh.2018.02.004.

Safer Chemicals, Healthy Families (2017). Who's minding the store? – ranking retailers on toxic chemicals. https://retailerreportcard.com/. Accessed 14 August 2018.

Santos, L.H.M.L.M., Araújo, A.N., Fachini, A., Pena, A., Delerue-Matos, C. and Montenegro, M.C.B.S.M. (2010). Ecotoxicological aspects related to the presence of pharmaceuticals in the aquatic environment. *Journal of Hazardous Materials* 175(1-3), 45-95. https://doi.org/10.1016/j.jhazmat.2009.10.100.

Sarwar, M. (2016). Indoor risks of pesticide uses are significantly linked to hazards of the family members. *Cogent Medicine*. Lee, A. (ed.) 3(1), 1-10. https://doi.org/10.1080/2331205X.2016.1155373.

Schecter, A., Kincaid, J., Quynh, H.T., Lanceta, J., Tran, H.T.T., Crandall, R., Shropshire, W. and Birnbaum, L.S. (2018). Biomonitoring of metals, polybrominated diphenyl ethers, polychlorinated biphenyls, and persistent pesticides in Vietnamese female electronic waste recyclers. *Journal of Occupational and Environmental Medicine* 60(2), 191-197. https://doi.org/10.1097/jom.0000000000001200.

Scheringer, M., Trier, X., Cousins, I.T., de Voogt, P., Fletcher, T., Wang, Z. and Webster, T.F. (2014). Helsingør Statement on poly- and perfluorinated alkyl substances (PFASs). *Chemosphere* 114, 337-339. https://doi.org/10.1016/J.CHEMOSPHERE.2014.05.044.

Schnur, J. and John, R.M. (2014). Childhood lead poisoning and the new Centers for Disease Control and Prevention guidelines for lead exposure. *Journal of the American Association of Nurse Practitioners* 26(5), 238-247. https://doi.org/10.1002/2327-6924.12112.

Scholz, N. (2016). *Setting Criteria on Endocrine Disruptors: Follow-up to the General Court Judgment*. Brussels: European Parliamentary Research Service. http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/581986/EPRS_BRI(2016)581986_EN.pdf.

Schug, T.T., Johnson, A.F., Birnbaum, L.S., Colborn, T., Guillette, L.J., Crews, D.P., Collins, T., Soto, A.M., vom Saal, F.S., McLachlan, J.A., Sonnenschein, C. and Heindel, J.J. (2016). Minireview: endocrine disruptors: past lessons and future directions. *Molecular Endocrinology* 30(8), 833-847. https://doi.org/10.1210/me.2016-1096.

Schulte, P.A., Roth, G., Hodson, L.L., Murashov, V., Hoover, M.D., Zumwalde, R., Kuempel, E.D., Geraci, C.L., Stefaniak, A.B., Castranova, V. and Howard, J. (2016). Taking stock of the occupational safety and health challenges of nanotechnology: 2000-2015. *Journal of Nanoparticle Research: An Interdisciplinary Forum for Nanoscale Science and Technology* 18(159), 1-21. https://doi.org/10.1007/s11051-016-3459-1.

Schwirn, K. and Völker, D. (2016). *Nanomaterials in the Environment – Current State of Knowledge and Regulations on Chemical Safety: Recommendations of the German Environment Agency*. Dessau-Roßlau: German Environment Agency https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/nanomaterials_in_the_environment.pdf.

Scientific Committee on Emerging and Newly Identified Health Risks (2009). *SCENIHR Risk Assessment of Products of Nanotechnologies*. Brussels: European Commission. http://ec.europa.eu/health/ph_risk/risk_en.htm.

Scruggs, C.E., Nimpuno, N. and Moore, R.B.B. (2016). Improving information flow on chemicals in electronic products and E-waste to minimize negative consequences for health and the environment. *Resources, Conservation and Recycling* 113, 149-164. https://doi.org/10.1016/J.RESCONREC.2016.06.009.

Scruggs, C.E., Ortolano, L., Schwarzman, M.R. and Wilson, M.P. (2014). The role of chemical policy in improving supply chain knowledge and product safety. *Journal of Environmental Studies and Sciences* 4(2), 132-141. https://doi.org/10.1007/s13412-013-0158-4.

Secretariat of the Basel Convention and United Nations Industrial Development Organization (2011). *Report of the International Workshop on Hazardous Substances within the Life-cycle of Electrical and Electronic Products, held in Vienna, from 29 to 31 March 2011*. Vienna: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/Documents/EPI/report%20e-waste%20workshop_vienna.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2009a). *Background Information in Relation to the Emerging Policy Issue of Chemicals in Products*. Geneva. http://www.saicm.org/Portals/12/documents/meetings/ICCM2/inf/ICCM2%20INF35%20products%20background%20E.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2009b). *Emerging Policy Issues*. Geneva. http://www.saicm.org/Portals/12/documents/meetings/ICCM2/doc/ICCM2%2010%20emerging%20issues%20E.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2015a). *Proposal on Highly Hazardous Pesticides*. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/doc/K1502177%20SAICM-ICCM4-8-e.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2015b). *Report of the International Conference on Chemicals Management on the Work of its Fourth Session*. http://www.unitar.org/cwm/sites/unitar.org.cwm/files/uploads/iccm4_adopted_resolution_on_nano.pdf.

Secretariat of the Strategic Approach to International and Chemicals Management (2015c). *Nomination for New Emerging Policy Issue: Environmentally Persistent Pharmaceutical Pollutants*. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/doc/K1502367%20SAICM-ICCM4-7-e.pdf.

Secretariat of the Strategic Approach to International Chemicals Management (2018). *Independent Evaluation of the Strategic Approach Draft Report*. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_4_Independent_Evaluation.pdf.

Segura, P.A., Takada, H., Correa, J.A., El Saadi, K., Koike, T., Onwona-Agyeman, S., Ofosu-Anim, J., Sabi, E.B., Wasonga, O. V., Mghalu, J.M., dos Santos, A.M., Newman, B., Weerts, S. and Yargeau, V. (2015). Global occurrence of anti-infectives in contaminated surface waters: Impact of income inequality between countries. *Environment International* 80, 89-97. https://doi.org/10.1016/J.ENVINT.2015.04.001.

Selin, H. and VanDeveer, S.D. (2006). Raising global standards: hazardous substances and e-waste management in the European Union. *Environment: Science and Policy for Sustainable Development* 48(10), 6-18. https://doi.org/10.3200/ENVT.48.10.6-18.

Senthil-Nathan, S. (2015). A review of biopesticides and their mode of action against insect pests. In *Environmental Sustainability*. New Delhi: Springer, 49-63. https://doi.org/10.1007/978-81-322-2056-5_3.

Solecki, R., Kortenkamp, A., Bergman, Å., Chahoud, I., Degen, G.H., Dietrich, D., Greim, H., Håkansson, H., Hass, U., Husoy, T., Jacobs, M., Jobling, S., Mantovani, A., Marx-Stoelting, P., Piersma, A., Ritz, V., Slama, R., Stahlmann, R., van den Berg, M., Zoeller, R.T. and Boobis, A.R. (2017). Scientific principles for the identification of endocrine-disrupting chemicals: a consensus statement. *Archives of Toxicology* 91(2), 1001-1006. https://doi.org/10.1007/s00204-016-1866-9.

Song, Q. and Li, J. (2014). A systematic review of the human body burden of e-waste exposure in China. *Environment International* 68, 82-93. https://doi.org/10.1016/J.ENVINT.2014.03.018.

Song, Q. and Li, J. (2015). A review on human health consequences of metals exposure to e-waste in China. *Environmental Pollution* 196, 450-461. https://doi.org/10.1016/j.envpol.2014.11.004.

Song, R., Qin, Y., Suh, S. and Keller, A.A. (2017). Dynamic model for the stocks and release flows of engineered nanomaterials. *Environmental Science & Technology* 51(21), 12424-12433. https://doi.org/10.1021/acs.est.7b01907.

State Council of China (2016). Circular of the state council on printing and distributing the "thirteenth five-year" ecological environmental protection plan. http://www.gov.cn/zhengce/content/2016-12/05/content_5143290.htm. Accessed 22 February 2018.

State of Minnesota (United States) (2018). *State of Minnesota, by its Attorney General, Lori Swanson, its Commissioner of Pollution Control, John Linc Stine, and its Commissioner of Natural Resources, Tom Landwehr vs 3M Company*. Hennepin County, MN. https://www.pca.state.mn.us/sites/default/files/c-pfc2-11f.pdf.

Stegon, D. (2017). DuPont, Chemours settle PFOA lawsuit for $670m, 16 February. *Chemical Watch*. https://chemicalwatch.com/53632/dupont-chemours-settle-pfoa-lawsuit-for-670m. Accessed 12 June 2018.

Stockholm County Council (2014). *Environmentally Classified Pharmaceuticals 2014-2015*. https://noharm-uscanada.org/documents/environmentally-classified-pharmaceuticals-2014-2015.

Stringer, L. (2018). Industry representatives start talks on cross-sector material declarations, 15 March. *Chemical Watch*. https://chemicalwatch.com/64946/industry-representatives-start-talks-on-cross-sector-material-declarations. Accessed 12 June 2018.

Sun, M., Arevalo, E., Strynar, M., Lindstrom, A., Richardson, M., Kearns, B., Pickett, A., Smith, C. and Knappe, D.R.U. (2016). Legacy and emerging perfluoroalkyl substances are important drinking water contaminants in the Cape Fear River Watershed of North Carolina. *Environmental Science & Technology Letters* 3(12), 415-419. https://doi.org/10.1021/acs.estlett.6b00398.

Sun, T.Y., Mitrano, D.M., Bornhöft, N.A., Scheringer, M., Hungerbühler, K. and Nowack, B. (2017). Envisioning nano release dynamics in a changing world: using dynamic probabilistic modeling to assess future environmental emissions of engineered nanomaterials. *Environmental Science & Technology* 51(5), 2854-2863. https://doi.org/10.1021/acs.est.6b05702.

Swedish Chemicals Agency (2015). Action plan for a toxic-free everyday environment 2015-2020. https://www.kemi.se/en/about-us/our-task/government-assignments/action-plan-for-a-toxic-free-everyday-environment. Accessed 11 June 2018.

Thompson, L.A., Darwish, W.S., Ikenaka, Y., Nakayama, S.M.M., Mizukawa, H. and Ishizuka, M. (2017). Organochlorine pesticide contamination of foods in Africa: incidence and public health significance. *Journal of Veterinary Medical Science* 79(4), 751-764. https://doi.org/10.1292/jvms.16-0214.

Tollefsen, K.E., Scholz, S., Cronin, M.T., Edwards, S.W., de Knecht, J., Crofton, K., Garcia-Reyero, N., Hartung, T., Worth, A. and Patlewicz, G. (2014). Applying Adverse Outcome Pathways (AOPs) to support Integrated Approaches to Testing and Assessment (IATA). *Regulatory Toxicology and Pharmacology* 70(3), 629-640. https://doi.org/10.1016/J.YRTPH.2014.09.009.

Tsydenova, O. and Bengtsson, M. (2011). Chemical hazards associated with treatment of waste electrical and electronic equipment. *Waste Management* 31(1), 45-58. https://doi.org/10.1016/J.WASMAN.2010.08.014.

Turner, A., Kearl, E.R. and Solman, K.R. (2016). Lead and other toxic metals in playground paints from South West England. *Science of the Total Environment* 544, 460-466. https://doi.org/10.1016/J.SCITOTENV.2015.11.078.

United Nations Environment Programme (2011). *A Synthesis of Findings Under the UNEP/IOMC Project on Information on Chemicals in Products*. https://www.saicm.org/Portals/12/documents/meetings/ICCM3/inf/ICCM3_INF20_CiP%20Project%20synthesis%20report.pdf.

United Nations Environment Programme (2015). *The Chemicals in Products Programme: Guidance for Stakeholders on Exchanging Chemicals in Products Information*. http://www.saicm.org/Portals/12/Documents/EPI/Guidance%20for%20Stakeholder%20in%20Exchanging%20CiP%20Information_October2015.pdf.

United Nations Environment Programme (2017a). *Update on the Global Status of Legal Limits on Lead in Paint: September 2017*. https://wedocs.unep.org/bitstream/handle/20.500.11822/22001/Glbbal%20Update%20Final%20Version%2011_Oct.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2017b). *Overview Report III: Existing National, Regional, and Global Regulatory Frameworks Addressing Endocrine Disrupting Chemicals (EDCs)*. https://wedocs.unep.org/bitstream/handle/20.500.11822/25636/edc_report3.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2017c). *Overview Report I: Worldwide Initiatives to Identify Endocrine Disrupting Chemicals (EDCs) and Potential EDCs The International Panel on Chemical Pollution (IPCP)*. https://wedocs.unep.org/bitstream/handle/20.500.11822/25633/EDC_report1.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme and International POPs Elimination Network (2013). *Lead in Enamel Decorative Paints: National Paint Testing Results - A Nine Country Study*. Geneva: United Nations Environment Programme. http://www.ipen.org/sites/default/files/documents/lead_in_enamel_decorative_paints-en.pdf.

United Nations Environment Programme and World Health Organization (2012). *Global Alliance to Eliminate Lead Paint: Business Plan*. http://www.who.int/ipcs/assessment/public_health/business_plan_en.pdf?ua=1.

United Nations Human Rights Council (2017). *Report of the Special Rapporteur on the Right to Food*. https://documents-dds-ny.un.org/doc/UNDOC/GEN/G17/017/85/PDF/G1701785.pdf?OpenElement.

United Nations Industrial Development Organization (2015). *Emerging Policy Issue Update on Hazardous Substances within the Life Cycle of Electrical and Electronic Products*. Geneva: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/inf/ICCM4_INF18_EPI%20HSLEEP.pdf.

United States Centers for Disease Control and Prevention (2010). Notice to readers: examining the effect of previously missing blood lead surveillance data on results reported in MMWR. *MMWR Weekly Report* 59 (19), 592. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5919a4.htm.

United States Centers for Disease Control and Prevention (2016). CDC investigation: blood lead levels higher after switch to Flint River water: stark reminder of dangers of lead exposure for young children, 25 June. https://www.cdc.gov/media/releases/2016/p0624-water-lead.html. Accessed 18 February 2019.

United States Environmental Protection Agency (2008). *TSCA Inventory Status of Nanoscale Substances - General Approach 2008*. https://www.epa.gov/sites/production/files/2015-10/documents/nmsp-inventorypaper2008.pdf.

United States Environmental Protection Agency (2013). *EPA's State of the Science Evaluation: Nonmonotonic Dose Responses as They Apply to Estrogen, Androgen, and Thyroid Pathways and EPA Testing and Assessment Procedures (Draft)*. https://www.epa.gov/sites/production/files/2016-01/documents/nmdr.pdf.

United States Environmental Protection Agency (2017a). Control of nanoscale materials under the toxic substances control act, 30 November. https://www.epa.gov/reviewing-new-chemicals-under-toxic-substances-control-act-tsca/control-nanoscale-materials-under. Accessed 14 August 2018.

United States Environmental Protection Agency (2017b). Endocrine disruptor screening program (EDSP) universe of chemicals, 22 February. https://www.epa.gov/endocrine-disruption/endocrine-disruptor-screening-program-edsp-universe-chemicals. Accessed 8 November 2018.

United States Environmental Protection Agency (2017c). Endocrine disruptor screening program (EDSP) policies and procedures, 22 February. https://www.epa.gov/endocrine-disruption/endocrine-disruptor-screening-program-edsp-policies-and-procedures. Accessed 14 November 2018.

United States Environmental Protection Agency (2017d). Use of high throughput assays and computational tools in the endocrine disruptor screening program, 22 February. https://www.epa.gov/endocrine-disruption/use-high-throughput-assays-and-computational-tools-endocrine-disruptor. Accessed 14 August 2018.

United States Environmental Protection Agency (2018). Risk management for per- and polyfluoroalkyl substances (PFASs) under TSCA: PFOA stewardship program. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfass#tab-3. Accessed 11 June 2018.

United States Food and Drug Administration (1998). *Guidance for Industry Environmental Assessment of Human Drug and Biologics Applications*. http://www.fda.gov/cder/guidance/index.htm.http://www.fda.gov/cber/guidelines.htm.Copiesalsomaybeobtainedbyfaxfrom1-888-CBERFAXor301-827-3844orfromVoiceInformationat800-835-4709or301-827-1800.

United States Food and Drug Administration (2017). Cosmetics & U.S. Law. *Center for Food Safety and Applied Nutrition*. https://www.fda.gov/Cosmetics/GuidanceRegulation/LawsRegulations/ucm2005209.htm. Accessed 17 November 2017.

United States National Toxicology Program (2012). *NTP Monograph on Health Effects of Low-Level Lead*. https://ntp.niehs.nih.gov/ntp/ohat/lead/final/monographhealtheffectslowlevellead_newissn_508.pdf.

van Rossem, C., Tojo, N. and Lindhqvist, T. (2006). *Extended Producer Responsibility an Examination of its Impact on Innovation and Greening Products*. Brussels and Amsterdam: European Environmental Bureau, Friends of the Earth Europe and Greenpeace International. https://www.lunduniversity.lu.se/lup/publication/7c4e1114-ce30-43b1-9aa6-aba51ba28940.

Vance, M.E., Kuiken, T., Vejerano, E.P., McGinnis, S.P., Hochella, M.F., Rejeski, D., Hull, M.S. and Hull, M.S. (2015). Nanotechnology in the real world: redeveloping the nanomaterial consumer products inventory. *Beilstein Journal of Nanotechnology* 6, 1769-1780. https://doi.org/10.3762/bjnano.6.181.

Vandenberg, L.N., Colborn, T., Hayes, T.B., Heindel, J.J., Jacobs, D.R., Lee, D.-H., Shioda, T., Soto, A.M., vom Saal, F.S., Welshons, W.V., Zoeller, R.T. and Myers, J.P. (2012). Hormones and endocrine-disrupting chemicals: low-dose effects and nonmonotonic dose responses. *Endocrine Reviews* 33(3), 378-455. https://doi.org/10.1210/er.2011-1050.

Verlicchi, P., Galletti, A. and Masotti, L. (2010). Management of hospital wastewaters: the case of the effluent of a large hospital situated in a small town. *Water Science & Technology* 61(10), 2507. https://doi.org/10.2166/wst.2010.138.

Verlicchi, P., Galletti, A., Petrovic, M. and Barceló, D. (2010). Hospital effluents as a source of emerging pollutants: an overview of micropollutants and sustainable treatment options. *Journal of Hydrology* 389(3-4), 416-428. https://doi.org/10.1016/J.JHYDROL.2010.06.005.

Verstraeten, S.V., Aimo, L. and Oteiza, P.I. (2008). Aluminium and lead: molecular mechanisms of brain toxicity. *Archives of Toxicology* 82(11), 789-802. https://doi.org/10.1007/s00204-008-0345-3.

Vinson, F., Merhi, M., Baldi, I., Raynal, H. and Gamet-Payrastre, L. (2011). Exposure to pesticides and risk of childhood cancer: a meta-analysis of recent epidemiological studies. *Occupational and Environmental Medicine* 68(9), 694-702. https://doi.org/10.1136/oemed-2011-100082.

Wang, D., Cai, Z., Jiang, G., Leung, A. and Wong, W.K. (2005). Determination of polybrominated diphenyl ethers in soil and sediment from an electronic waste recycling facility. *Chemosphere* 60(6), 810-816. https://doi.org/10.1016/J.CHEMOSPHERE.2005.04.025.

Wang, Z., Boucher, J.M., Scheringer, M., Cousins, I.T. and Hungerbühler, K. (2017a). Toward a comprehensive global emission inventory of C4–C10 perfluoroalkanesulfonic acids (PFSAs) and related precursors: focus on the life cycle of C8-based products and ongoing industrial transition. *Environmental Science & Technology* 51(8), 4482-4493. https://doi.org/10.1021/acs.est.6b06191.

Wang, Z., Cousins, I.T., Berger, U., Hungerbühler, K. and Scheringer, M. (2016). Comparative assessment of the environmental hazards of and exposure to perfluoroalkyl phosphonic and phosphinic acids (PFPAs and PFPiAs): current knowledge, gaps, challenges and research needs. *Environment International* 89-90, 235-247. https://doi.org/10.1016/J.ENVINT.2016.01.023.

Wang, Z., Cousins, I.T., Scheringer, M. and Hungerbuehler, K. (2015). Hazard assessment of fluorinated alternatives to long-chain perfluoroalkyl acids (PFAAs) and their precursors: status quo, ongoing challenges and possible solutions. *Environment International* 75, 172-179. https://doi.org/10.1016/J.ENVINT.2014.11.013.

Wang, Z., Cousins, I.T., Scheringer, M., Buck, R.C. and Hungerbühler, K. (2014). Global emission inventories for C4–C14 perfluoroalkyl carboxylic acid (PFCA) homologues from 1951 to 2030, Part I: production and emissions from quantifiable sources. *Environment International* 70, 62-75. https://doi.org/10.1016/J.ENVINT.2014.04.013.

Wang, Z., DeWitt, J.C., Higgins, C.P. and Cousins, I.T. (2017b). A never-ending story of per- and polyfluoroalkyl substances (PFASs)? *Environmental Science & Technology* 51(5), 2508-2518. https://doi.org/10.1021/acs.est.6b04806.

Weiss, F.T., Leuzinger, M., Zurbrügg, C. and Eggen, R.I.L. (2016). *Chemical Pollution in Low- and Middle-Income Countries*. Dübendorf: Swiss Federal Institute of Aquatic Science and Technology. https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/publikationen/Chemical_Pollution/Lamics-WEB.pdf.

Williams, M., Backhaus, T., Bowe, C., Choi, K., Connors, K., Hickmann, S., Hunter, W., Kookana, R., Marfil-Vega, R. and Verslycke, T. (2016). Pharmaceuticals in the environment: an introduction to the ET&C special issue. *Environmental Toxicology and Chemistry* 35(4), 763-766. https://doi.org/10.1002/etc.3394.

World Health Organization (2002). *Global Assessment of the State-of-the-Science of Endocrine Disruptors*. Damstra, T., Barlow, S., Bergman, A., Kavlock, R., Van, G. and Kraak, D. (eds.). http://www.who.int/ipcs/publications/en/toc.pdf.

World Health Organization (2010a). *Childhood Lead Poisoning*. http://www.who.int/ceh/publications/leadguidance.pdf.

World Health Organization (2010b). *Exposure to Lead: A Major Public Health Concern*. http://www.who.int/ipcs/features/lead..pdf?ua=1.

World Health Organization (2014). *Antimicrobial Resistance: Global Report on Surveillance*. http://apps.who.int/iris/bitstream/handle/10665/112642/9789241564748_eng.pdf?sequence=1.

World Health Organization (2015). *Global Action Plan on Antimicrobial Resistance*. https://apps.who.int/iris/bitstream/handle/10665/193736/9789241509763_eng.pdf?sequence=1.

World Health Organization (2016). *The Public Health Impact of Chemicals: Knowns and Unknowns*. http://apps.who.int/iris/bitstream/handle/10665/206553/WHO_FWC_PHE_EPE_16.01_eng.pdf?sequence=1.

World Health Organization (2017a). Global health observatory (GHO) data: Countries and territories with legally-binding controls on lead paint. http://www.who.int/gho/phe/chemical_safety/lead_paint_regulations/en/. Accessed 11 June 2018.

World Health Organization (2017b). *WHO Guidelines on use of Medically Important Antimicrobials in Food-Producing Animals*. https://www.who.int/foodsafety/areas_work/antimicrobial-resistance/cia_guidelines/en/.

World Health Organization (2017c). Nanotechnologies: WHO guidelines on nanomaterials and workers' health. http://www.who.int/occupational_health/topics/nanotechnologies/en/. Accessed 5 December 2017.

World Health Organization (2017d). *WHO Guidelines on Protecting Workers from Potential of Manufactured Nanomaterials*. http://apps.who.int/iris/bitstream/handle/10665/259671/9789241550048-eng.pdf;jsessionid=2FD1722707BDE8E98B9B1D9F345DE46E?sequence=1.

World Health Organization (2018a). Global health observatory (GHO) data: legislation - regulations and controls on lead paint. http://www.who.int/gho/phe/chemical_safety/lead_paint_regulations/en/. Accessed 6 January 2019.

World Health Organization (2018b). *Global Report on Insecticide Resistance in Malaria Vectors: 2010-2016 - Global Malaria Programme*. http://apps.who.int/iris/bitstream/handle/10665/272533/9789241514057-eng.pdf?ua=1.

World Health Organization (2018c). *World Health Statistics 2018: Monitoring Health for the SDGs, Sustainable Development Goals*. http://apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf?ua=1.

World Health Organization and Food and Agriculture Organization of the United Nations (2016). *Manual on Development and Use of FAO and WHO Specifications for Pesticides – Third Revision. 1st edn*. http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Specs/JMPS_Manual_2016/3rd_Amendment_JMPS_Manual.pdf.

World Health Organization and United Nations Environment Programme (2009). *Background Information in Relation to the Emerging Policy Issue of Lead in Paint*. Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/ICCM2/inf/ICCM2%20INF38%20lead%20in%20paint%20background.pdf.

World Health Organization and United Nations Environment Programme (2012). *Progress Report on the Implementation of Resolution II/4 B on Lead in Paint*. Nairobi: Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/ICCM3/doc/SAICM_ICCM3_14_EN.pdf.

Xiao, X., Ulrich, B.A., Chen, B. and Higgins, C.P. (2017). Sorption of poly- and perfluoroalkyl substances (PFASs) relevant to aqueous film-forming foam (AFFF)-impacted groundwater by biochars and activated carbon. *Environmental Science & Technology* 51(11), 6342-6351. https://doi.org/10.1021/acs.est.7b00970.

Xu, X., Liao, W., Lin, Y., Dai, Y., Shi, Z. and Huo, X. (2017). Blood concentrations of lead, cadmium, mercury and their association with biomarkers of DNA oxidative damage in preschool children living in an e-waste recycling area. *Environmental Geochemistry and Health* 1-14. https://doi.org/10.1007/s10653-017-9997-3.

Yadav, I.C., Devi, N.L., Syed, J.H., Cheng, Z., Li, J., Zhang, G and Jones, K.C. (2015). Current status of persistent organic pesticides residues in air, water, and soil, and their possible effect on neighboring countries: A comprehensive review of India. *Science of the Total Environment* 511, 123-137. https://doi.org/10.1016/j.scitotenv.2014.12.041.

Yu, G., Bu, Q., Cao, Z., Du, X., Xia, J., Wu, M. and Huang, J. (2016). Brominated flame retardants (BFRs): a review on environmental contamination in China. *Chemosphere* 150, 479-490. https://doi.org/10.1016/J.CHEMOSPHERE.2015.12.034.

Zheng, J., Yu, L.-H., Chen, S.-J., Hu, G.-C., Chen, K.-H., Yan, X., Luo, X.-J., Zhang, S., Yu, Y.-J., Yang, Z.-Y. and Mai, B.-X. (2016). Polychlorinated Biphenyls (PCBs) in human hair and serum from e-waste recycling workers in southern China: concentrations, chiral signatures, correlations, and source identification. *Environmental Science & Technology* 50(3), 1579-1586. https://doi.org/10.1021/acs.est.5b04955.

Zheng, X., Sun, R., Qiao, L., Guo, H., Zheng, J. and Mai, B. (2017). Flame retardants on the surface of phones and personal computers. *Science of the Total Environment* 609, 541-545. https://doi.org/10.1016/j.scitotenv.2017.07.202.

## Chapter 5

Acquavella, J., Garabrant, D., Marsh, G., Sorahan, T. and Weed, D.L. (2016). Glyphosate epidemiology expert panel review: a weight of evidence systematic review of the relationship between glyphosate exposure and non-hodgkin's lymphoma or multiple myeloma. *Critical Reviews in Toxicology* 46(sup1), 28-43. https://doi.org/10.1080/10408444.2016.1214681.

Albert, O. and Jégou, B. (2014). A critical assessment of the endocrine susceptibility of the human testis to phthalates from fetal life to adulthood. *Human Reproduction Update* 20(2), 231-249. https://doi.org/10.1093/humupd/dmt050.

Andersen, J.H., Asplund, L., Berger, U., Bignert, A., Boalt, E., Broeg, K., Brzozowska, A., Cato, I., Durkin, M., Garnaga, G., Gustavson, K., Haarich, M., Hedlund, B., Köngäs, P., Lang, T., Larsen, M.M., Lehtonen, K., Mannio, J., Mehtonen, J., Murray, C., Nielsen, Sven Nyström, B., Pazdro, K., Ringeltaube, P., Schiedek, D., Schneider, R., Stankiewicz, M., Strand, J., Sundelin, B., Söderström, M., Vallius, H., Vanninen, P., Verta, M., Vieno, N., Vuorinen Pekka J. and Zahharov, A. (2010). *Hazardous Substances in the Baltic Sea: An Integrated Thematic Assessment of Hazardous Substances in the Baltic Sea*. Baltic Sea Environment Proceedings No. 120B. Korpinen, S. and Laamanen, M. (eds.). Helsinki: Helsinki Commission. http://www.helcom.fi/lists/publications/bsep120b.pdf.

Aranami, K. and Readman, J.W. (2007). Photolytic degradation of triclosan in freshwater and seawater. *Chemosphere* 66(6), 1052-1056. https://doi.org/10.1016/J.CHEMOSPHERE.2006.07.010.

Beaman, J., Benson, R., Cook, A.-M., Gallagher, K., Ho, K., Hoff, D. and Laessig, S. (2016). *State of the Science White Paper: A Summary of Literature on the Chemical Toxicity of Plastics Pollution to Aquatic Life and Aquatic-Dependent Wildlife*. Washington, D.C.: United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2016-12/documents/plastics-aquatic-life-report.pdf.

Benbrook, C.M. (2016). Trends in glyphosate herbicide use in the United States and globally. *Environmental Sciences Europe* 28(1), 1-15. https://doi.org/10.1186/s12302-016-0070-0.

Biedermann, S., Tschudin, P. and Grob, K. (2010). Transfer of bisphenol A from thermal printer paper to the skin. *Analytical and Bioanalytical Chemistry* 398(1), 571-576. https://doi.org/10.1007/s00216-010-3936-9.

Biedermann-Brem, S., Biedermann, M., Pfenninger, S., Bauer, M., Altkofer, W., Rieger, K., Hauri, U., Droz, C. and Grob, K. (2008). European Union risk assessment report on Bis(2-Ethylhexyl) phthalate (DEHP), 2008. *Chromatographia* 68(3-4), 227-234. https://doi.org/10.1365/s10337-008-0672-9.

Boucher, J. and Friot, D. (2017). *Primary Microplastics in the Oceans: Global Evaluation of Sources*. Lundin, C. G. and Sousa, J. M. de (eds). Gland: International Union for Conservation of Nature and Natural Resources. https://doi.org/10.2305/iucn.ch.2017.01.en.

Bouwman, H. (2012). *GEF Guidance on Emerging Chemicals Management Issues in Developing Countries and Countries with Economies in Transition*. Washington, D.C.: Scientific and Technical Advisory Panel. https://www.thegef.org/sites/default/files/publications/GEF_Guidance_on_Emerging_Chemicals-Full-Report_0.pdf.

Brande-Lavridsen, N. (n.d.). *Microplastics in the Freshwater Environment*. Knoxville, TN: University of Tennessee. https://www.epa.gov/sites/production/files/2017-01/documents/microplastics-in-freshwater-environment.pdf.

Carlisle, J., Chan, D., Golub, M., Henkel, S., Painter, P. and Wu, K.L. (2009). *Toxicological Profile for Bisphenol A*. Sacramento, CA: California Environmental Protection Agency. http://www.opc.ca.gov/webmaster/ftp/project_pages/MarineDebris_OEHHA_ToxProfiles/Bisphenol%20A%20Final.pdf.

Chang, E.T. and Delzell, E. (2016). Systematic review and meta-analysis of glyphosate exposure and risk of lymphohematopoietic cancers. *Journal of Environmental Science and Health, Part B* 51(6), 402-434. https://doi.org/10.1080/03601234.2016.1142748.

Cimino, A.M., Boyles, A.L., Thayer, K.A. and Perry, M.J. (2017). Effects of neonicotinoid pesticide exposure on human health: A systematic review. *Environmental Health Perspectives* 125(2), 155-162. http://dx.doi.org/10.1289/EHP515.

Cole, R.F., Mills, G.A., Parker, R., Bolam, T., Birchenough, A., Kröger, S. and Fones, G.R. (2015). Trends in the analysis and monitoring of organotins in the aquatic environment. *Trends in Environmental Analytical Chemistry* 8, 1-11. https://doi.org/10.1016/j.teac.2015.05.001.

Conrad, A., Schröter-Kermani, C., Hoppe, H.-W., Rüther, M., Pieper, S. and Kolossa-Gehring, M. (2017). Glyphosate in german adults – time trend (2001 to 2015) of human exposure to a widely used herbicide. *International Journal of Hygiene and Environmental Health* 220(1), 8-16. https://doi.org/10.1016/j.ijheh.2016.09.016.

Crampton, L. (2017). Microplastics in the environment and in the human body, 12 September. https://owlcation.com/stem/Microplastics-in-the-Human-Body-and-Potential-Health-Effects. Accessed 14 June 2018.

de Miranda, J.R. and Nazzi, F. (2017). Multiple stressors, neonicotinoid insecticides and bee declines. *Science* 356(6345), Letters. https://pub.epsilon.slu.se/15318/1/de_miranda_et_al_180507.pdf.

Den Hond, E., Govarts, E., Willems, H., Smolders, R., Casteleyn, L., Kolossa-Gehring, M., Schwedler, G., Seiwert, M., Fiddicke, U., Castaño, A., Esteban, M., Angerer, J., Koch, H.M., Schindler, B.K., Sepai, O., Exley, K., Bloemen, L., Horvat, M., Knudsen, L.E., Joas, A., Joas, R., Biot, P., Aerts, D., Koppen, G., Katsonouri, A., Hadjipanayis, A., Krskova, A., Maly, M., Mørck, T.A., Rudnai, P., Kozepesy, S., Mulcahy, M., Mannion, R., Gutleb, A.C., Fischer, M.E., Ligocka, D., Jakubowski, M., Reis, M.F., Namorado, S., Gurzau, A.E., Lupsa, I.R., Halzlova, K., Jajcaj, M., Mazej, D., Tratnik, J.S., López, A., Lopez, E., Berglund, M., Larsson, K., Lehmann, A., Crettaz, P. and Schoeters, G. (2015). First steps toward harmonized human biomonitoring in Europe: demonstration project to perform human biomonitoring on a European scale. *Environmental Health Perspectives* 123(3), 255-263. https://doi.org/10.1289/ehp.1408616.

Deng, T., Wu, L., Gao, J.-M., Zhou, B., Zhang, Y.-L., Wu, W.-N., Tang, Z.-H., Jiang, W.-C. and Huang, W.-L. (2018). Occurrence and health risk assessment of organotins in waterworks and the source water of the Three Gorges Reservoir Region, China. *Environmental Science and Pollution Research* 25(15), 15019-15028. https://doi.org/10.1007/s11356-018-1704-0.

Dhillon, G.S., Kaur, S., Pulicharla, R., Brar, S.K., Cledón, M., Verma, M. and Surampalli, R.Y. (2015). Triclosan: current status, occurrence, environmental risks and bioaccumulation potential. *International Journal of Environmental Research and Public Health* 12(5), 5657-5684. https://doi.org/10.3390/ijerph120505657.

Duchet, C., Kraft, A. and Stark, J.D. (2018). Effects of environmentally realistic concentrations of neonicotinoid insecticides on an aquatic invertebrate community. Seattle, WA: Salish Sea Ecosystem Conference. Western Washington University. https://cedar.wwu.edu/cgi/viewcontent.cgi?article=2833&context=ssec.

Ejaredar, M., Lee, Y., Roberts, D.J., Sauve, R. and Dewey, D. (2017). Bisphenol a exposure and children's behavior: a systematic review. *Journal of Exposure Science & Environmental Epidemiology* 27(2), 175-183. https://doi.org/10.1038/jes.2016.8.

Ena, L., Lim, J.S., Son, J.Y., Park, Y.J., Lee, Y.H., Kim, J.Y., Kwack, S.J., Lee, B.M., Ahn, M.-Y. and Kim, H.S. (2018). Evaluation of subchronic exposure to triclosan on hepatorenal and reproductive toxicities in prepubertal male rats. *Journal of Toxicology and Environmental Health, Part A* 81(11), 421-431. https://doi.org/10.1080/15287394.2018.1451188.

Environment and Climate Change Canada (2015). Microbeads – a science summary, 30 July. https://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=ADDA4C5F-1#s02. Accessed 20 February 2019.

Essel, R., Engel, L., Carus, M. and Heinrich Ahrens, R. (2015). *Sources of Microplastics Relevant to Marine Protection in Germany*. Werner, S. (ed.). Dessau-Roßlau: German Environment Agency. https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_64_2015_sources_of_microplastics_relevant_to_marine_protection_1.pdf.

European Chemicals Agency (2017). Glyphosate not classified as a carcinogen by ECHA, 15 March. https://echa.europa.eu/de/-/glyphosate-not-classified-as-a-carcinogen-by-echa. Accessed 13 June 2018.

European Chemicals Bureau (2008). *European Union Risk Assessment Report on Bis(2-Ethylhexyl) Phthalate (DEHP), 2008*. https://echa.europa.eu/documents/10162/e614617d-58e7-42d9-b7fb-d7bab8f26feb.

European Food Safety Authority (2015). *Glyphosate: EFSA Explains Risk Assessment*. https://doi.org/10.2805/654221.

Feng, Y., Zhang, P., Zhang, Z., Shi, J., Jiao, Z. and Shao, B. (2016). Endocrine disrupting effects of triclosan on the placenta in pregnant rats. *PLoS ONE* 11(5), 1-14. https://doi.org/10.1371/journal.pone.0154758.

Food and Agriculture Organization of the United Nations and World Health Organization (2016). *Joint FAO/WHO Meeting on Pesticide Residues: Summary Report*. http://www.who.int/foodsafety/areas_work/chemical-risks/jmpr/en/.

Frederiksen, H., Nielsen, J.K.S., Mørck, T.A., Hansen, P.W., Jensen, J.F., Nielsen, O., Andersson, A.-M. and Knudsen, L.E. (2013). Urinary excretion of phthalate metabolites, phenols and parabens in rural and urban Danish mother–child pairs. *International Journal of Hygiene and Environmental Health* 216(6), 772-783. https://doi.org/10.1016/J.IJHEH.2013.02.006.

Friege, H., Zeschmar-Lahl, B. and Borgmann, A. (2018). Managing cd containing waste—caught by the past, the circular economy needs new answers. *Recycling* 3(2), 18. https://doi.org/10.3390/recycling3020018.

Gallego, S.M., Pena, L.B., Barcia, R.A., Azpilicueta, C.E., Iannone, M.F., Rosales, E.P., Zawoznik, M.S., Groppa, M.D. and Benavides, M.P. (2012). Unravelling cadmium toxicity and tolerance in plants: insight into regulatory mechanisms. *Environmental and Experimental Botany* 83, 33-46. https://doi.org/10.1016/J.ENVEXPBOT.2012.04.006.

Gallo, F., Fossi, C., Weber, R., Santillo, D., Sousa, J., Ingram, I., Nadal, A. and Romano, D. (2018). Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. *Environmental sciences Europe* 30(1), 13. https://doi.org/10.1186/s12302-018-0139-z.

GBD 2015 Risk Factors Collaborators(2016). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *The Lancet* 388(10053), 1659-1724. https://doi.org/10.1016/S0140-6736(16)31679-8.

Geiss, O., Bianchi, I., Senaldi, C., Lucena, A., Tirendi, S. and Barrero-Moreno, J. (2017). Skin surface film liquid as new migration medium for the determination of PAHs released from rubber containing consumer goods. *Polycyclic Aromatic Compounds* 1-10. https://doi.org/10.1080/10406638.2018.1458742.

German Environment Agency (2016). *Polycyclic Aromatic Hydrocarbons: Harmful to the Environment! Toxic! Inevitable?* Brandt, M. and Einhenkel-Arle, D. (eds). https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/polycyclic_aromatic_hydrocarbons_web.pdf.

Gillezeau, C., van Gerwen, M., Shaffer, R.M., Rana, I., Zhang, L., Sheppard, L. and Taioli, E. (2019). The evidence of human exposure to glyphosate: a review. *Environmental Health* 18(1), 2. https://doi.org/10.1186/s12940-018-0435-5.

Goldsmith, M.-R., Grulke, C.M., Brooks, R.D., Transue, T.R., Tan, Y.M., Frame, A., Egeghy, P.P., Edwards, R., Chang, D.T., Tornero-Velez, R., Isaacs, K., Wang, A., Johnson, J., Holm, K., Reich, M., Mitchell, J., Vallero, D.A., Phillips, L., Phillips, M., Wambaugh, J.F., Judson, R.S., Buckley, T.J. and Dary, C.C. (2014). Development of a consumer product ingredient database for chemical exposure screening and prioritization. *Food and Chemical Toxicology* 65, 269-279. https://doi.org/10.1016/J.FCT.2013.12.029.

Halden, R.U., Lindeman, A.E., Aiello, A.E., Andrews, D., Arnold, W.A., Fair, P., Egeghy, P.P., Edwards, R., Chang, D.T., Tornero-Velez, R., Isaacs, K., Wang, A., Johnson, J., Holm, K., Reich, M., Mitchell, J., Vallero, D.A., Phillips, L., Phillips, M., Wambaugh, J.F., Judson, R.S., Buckley, T.J. and Dary, C.C. (2017). The florence statement on triclosan and triclocarban. *Environmental Health Perspectives* 125(6), 064501 1-13. https://doi.org/10.1289/EHP1788.

Hartmann, C., Uhl, M., Weiss, S., Scharf, S. and König, J. (2018). Austrian reference values for phthalate metabolite exposure in children/adolescents and adults. *International Journal of Hygiene and Environmental Health* 221(6), 985-989. https://doi.org/10.1016/J.IJHEH.2018.06.001.

Health Canada (2017a). Re-evaluation decision RVD2017-01, glyphosate, 28 April. https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/registration-decision/2017/glyphosate-rvd-2017-01.html. Accessed 20 February 2019.

Health Canada (2017b). Update on the neonicotinoid pesticides, 19 December. https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/fact-sheets-other-resources/update-neonicotinoid-pesticides.html. Accessed 20 February 2019.

Health Canada (2019). Statement from Health Canada on glyphosate, 1 November. https://www.canada.ca/en/health-canada/news/2019/01/statement-from-health-canada-on-glyphosate.html. Accessed 31 March 2019.

Hopf, N.B., Berthet, A., Vernez, D., Langard, E., Spring, P. and Gaudin, R. (2014). Skin permeation and metabolism of di(2-ethylhexyl) phthalate (DEHP). *Toxicology Letters* 224(1), 47-53. https://doi.org/10.1016/J.TOXLET.2013.10.004.

Huang, R., Liu, Z., Yuan, S., Yin, H., Dang, Z. and Wu, P. (2017). Worldwide human daily intakes of bisphenol A (BPA) estimated from global urinary concentration data (2000–2016) and its risk analysis. *Environmental Pollution* 230, 143-152. https://doi.org/10.1016/j.envpol.2017.06.026.

Huang, X., Wu, C., Xiong, X., Zhang, K. and Liu, J. (2014). Partitioning and degradation of triclosan and formation of methyl-triclosan in water-sediment systems. *Water, Air, & Soil Pollution* 225(2099) 1-10. https://doi.org/10.1007/s11270-014-2099-2.

Huang, X., Wu, C., Hu, H., Yu, Y. and Liu, J. (2015). Sorption and degradation of triclosan in sediments and its effect on microbes. *Ecotoxicology and Environmental Safety* 116, 76-83. https://doi.org/10.1016/J.ECOENV.2015.03.002.

Hwang, S., Lim, J., Choi, Y. and Jee, S.H. (2018). Bisphenol a exposure and type 2 diabetes mellitus risk: a meta-analysis. *BMC Endocrine Disorders* 18(81), 1-10. https://doi.org/10.1186/s12902-018-0310-y.

IHS Markit (2018). Plasticizers, May 2018. *Chemical Economics Handbook*. https://ihsmarkit.com/products/plasticizers-chemical-economics-handbook.html. Accessed 25 August 2018.

International Agency for Research on Cancer (2012a). *Arsenic and Arsenic Compounds*. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C-6.pdf.

International Agency for Research on Cancer (2012b). *Cadmium and Cadmium Compounds*. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C-8.pdf.

International Agency for Research on Cancer (2015). *IARC Monographs Vol. 112: Evaluation of Five Organophosphate Insecticides and Herbicides*. http://www.iarc.fr/en/media-centre/iarcnews/pdf/MonographVolume112.pdf.

International Lead and Zinc Study Group (2018). Lead and zinc statistics. http://www.ilzsg.org/static/statistics.aspx. Accessed 22 May 2018.

Jeschke, P., Nauen, R., Schindler, M. and Elbert, A. (2011). Overview of the Status and Global Strategy for Neonicotinoids. *Journal of Agricultural and Food Chemistry* 59(7), 2897-2908. https://doi.org/10.1021/jf101303g.

Koch, H.M., Kolossa-Gehring, M., Schröter-Kermani, C. and Angerer, J. (2012). Bisphenol A in 24 h urine and plasma samples of the German Environmental Specimen Bank from 1995 to 2009: a retrospective exposure evaluation. *Journal of Exposure Science and Environmental Epidemiology* 22, 610-616. https://doi.org/10.1038/jes.2012.39.

Korfali, S.I., Sabra, R., Jurdi, M. and Taleb, R.I. (2013). Assessment of toxic metals and phthalates in children's toys and clays. *Archives of Environmental Contamination and Toxicology* 65(3), 368-381. https://doi.org/10.1007/s00244-013-9925-1.

Kumar, A. and Pastore, P. (2007). Lead and cadmium in soft plastic toys. *Current Science* 93(6), 818-822. https://www.calepa.ca.gov/wp-content/uploads/sites/62/2016/10/CEPC-2010yr-AsltonBird-AppAEx10.pdf.

Kumar, P. and Singh, A. (2010). Cadmium toxicity in fish: an overview. *GERF Bulletin of Biosciences* 1(1), 41-47. http://www.academia.edu/2346003/Cadmium_toxicity_in_fish_An_overview.

Landrigan, P.J., Fuller, R., Acosta, N.J.R., Adeyi, O., Arnold, R., Basu, N.N., Baldé, A.B., Bertollini, R., Bose-O'Reilly, S., Boufford, J.I., Breysse, P.N., Chiles, T., Mahidol, C., Coll-Seck, A.M., Cropper, M.L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., Hanrahan, D., Hunter, D., Khare, M., Krupnick, A., Lanphear, B., Lohani, B., Martin, K., Mathiasen, K. V, McTeer, M.A., Murray, C.J.L., Ndahimananjara, J.D., Perera, F., Potočnik, J., Preker, A.S., Ramesh, J., Rockström, J., Salinas, C., Samson, L.D., Sandilya, K., Sly, P.D., Smith, K.R., Steiner, A., Stewart, R.B., Suk, W.A., van Schayck, O.C.P., Yadama, G.N., Yumkella, K. and Zhong, M. (2018). The *Lancet* Commission on Pollution and Health. *The Lancet* 391(10119), 462-512. https://doi.org/10.1016/S0140-6736(17)32345-0.

Lassen, C., Hansen, S.F., Magnusson, K., Hartmann, N.B., Rehne Jensen, P., Nielsen, T.G. and Brinch, A. (2018). *Microplastics: Occurrence, Effects and Sources of Releases to the Environment in Denmark*. Copenhagen: Danish Environmental Protection Agency. http://orbit.dtu.dk/files/118180844/Lassen_et_al._2015.pdf.

Latch, D.E., Packer, J.L., Stender, B.L., VanOverbeke, J., Arnold, W.A. and McNeill, K. (2005). Aqueous photochemistry of triclosan: Formation of 2,4‐dichlorophenol, 2,8‐dichlorodibenzo‐p‐dioxin, and oligomerization products. *Environmental Toxicology and Chemistry* 24(3), 517-525. https://doi.org/10.1897/04-243R.1.

Liao, C. and Kannan, K. (2011). High levels of bisphenol A in paper currencies from several countries, and implications for dermal exposure. *Environmental Science & Technology* 45(16), 6761-6768. https://doi.org/10.1021/es200977t.

Magnusson, K. and Norén, F. (2014). *Screening of Microplastic Particles in and Down-stream a Wastewater Treatment Plant*. C 55. Stockholm: IVL Swedish Environmental Research Institute. https://www.diva-portal.org/smash/get/diva2:773505/FULLTEXT01.pdf.

Markets and Markets (2017). Glyphosate market by crop type, application, region – 2022. https://www.marketsandmarkets.com/Market-Reports/glyphosate-market-8522593.html. Accessed 2 May 2018.

Mendum, T., Stoler, E., VanBenschoten, H. and Warner, J.C. (2011). Concentration of bisphenol A in thermal paper. *Green Chemistry Letters and Reviews* 4(1), 81-86. https://doi.org/10.1080/17518253.2010.502908.

Mercea, P. (2009). Physicochemical processes involved in migration of bisphenol A from polycarbonate. Journal of Applied Polymer Science 112(2), 579-593. https://doi.org/10.1002/app.29421.

Morrall, D., McAvoy, D., Schatowitz, B., Inauen, J., Jacob, M., Hauk, A. and Eckhoff, W. (2004). A field study of triclosan loss rates in river water (Cibolo Creek, TX). *Chemosphere* 54(5), 653-660. https://doi.org/10.1016/J.CHEMOSPHERE.2003.08.002.

Murphy, F., Ewins, C., Carbonnier, F. and Quinn, B. (2016). Wastewater treatment works (WwTW) as a source of microplastics in the aquatic environment. *Environmental Science & Technology* 50, 5800-5808. https://doi.org/10.1021/acs.est.5b05416.

National Pollutant Inventory of Australia (2019). Organo-tin compounds, 18 January. http://www.npi.gov.au/resource/organo-tin-compounds. Accessed 19 February 2019.

Nerland, I.L., Halsband, C., Allan, I., Thomas, K. V and Thomas Kristoffer Naes, K. (2014). *Microplastics in marine environments: Occurrence, distribution and effects*. Oslo: Norwegian Institute for Water Research. http://www.miljodirektoratet.no/Documents/publikasjoner/M319/M319.pdf.

Nunes-Silva, A., Dittz, D., Santana, H.S., Faria, R.A., Freitas, K.M., Coutinho, C.R., de Melo Rodrigues, L.C., Miranda-Alves, L., Silva, I.V., Graceli, J.B. and Freitas Lima, L.C. (2018). The pollutant organotins leads to respiratory disease by inflammation: a mini-review. *Frontiers in Endocrinology* 8, 369. https://doi.org/10.3389/fendo.2017.00369.

O'Rourke, M.K., Van de Water, P.K., Jin, S., Rogan, S.P., Weiss, A.D., Gordon, S.M., Moschandreas, D.M. and Lebowitz, M.D. (1999). Evaluations of primary metals from NHEXAS Arizona: Distributions and preliminary exposures. *Journal of Exposure Analysis and Environmental Epidemiology* 9(5), 435-445. http://www.ncbi.nlm.nih.gov/pubmed/10554146.

Olaniyan, L.W.B., Mkwetshana, N. and Okoh, A.I. (2016). Triclosan in water, implications for human and environmental health. *SpringerPlus* 5(1639), 1-17. https://doi.org/10.1186/s40064-016-3287-x.

Omolaoye, J.A., Uzairu, J.O.A. and Gimba, C.E. (2010). Heavy metal assessment of some soft plastic toys imported into Nigeria from China. *Journal of Environmental Chemistry and Ecotoxicology* 2(8), 126-130. http://www.academicjournals.org/article/article1379515824_Omolaoye%20et%20al.pdf.

Paschke, M., Hutzler, C., Brinkmann, J., Henkler, F. and Luch, A. (2013). Polycyclic aromatic hydrocarbons in newspaper Inks: migration, metabolism, and genotoxicity in human skin. *Polycyclic Aromatic Compounds* 35(1), 32-40. https://doi.org/10.1080/10406638.2014.900643.

PR Newswire (2018). Global motive lead-acid battery market, 1 May. https://www.prnewswire.com/news-releases/global-motive-lead-acid-battery-market-2018-2022-300638339.html . Accessed 2 May 2018.

Puñal de Araújo, J.F., Podratz, P.L., Merlo, E., Sarmento, I.V., da Costa, C.S., Niño, O.M.S., Faria, R.A., Freitas Lima, L.C. and Graceli, J.B. (2018). Organotin exposure and vertebrate reproduction: a review. *Frontiers in Endocrinology* 9, 64. https://doi.org/10.3389/fendo.2018.00064.

Research and Markets (2018). Global Bisphenol A (BPA) market – segmented by application and geography – growth, trends, and forecast (2018-2023), April. https://www.researchandmarkets.com/research/pcjqf4/global_bisphenol?w=4. Accessed 26 September 2018.

Rochester, J.R. and Bolden, A.L. (2015). Bisphenol S and F: a systematic review and comparison of the hormonal activity of bisphenol A substitutes. Environmental Health Perspectives 123(7), 643-50. https://doi.org/10.1289/ehp.1408989.

Rortais, A., Arnold, G., Dorne, J.-L., More, S.J., Sperandio, G., Streissl, F., Szentes, C. and Verdonck, F. (2017). Risk assessment of pesticides and other stressors in bees: principles, data gaps and perspectives from the European Food Safety Authority. *Science of The Total Environment* 587-588, 524-537. https://doi.org/10.1016/j.scitotenv.2016.09.127.

Rundlöf, M., Andersson, G.K.S., Bommarco, R., Fries, I., Hederström, V., Herbertsson, L., Jonsson, O., Klatt, B.K., Pedersen, T.R., Yourstone, J. and Smith, H.G. (2015). Seed coating with a neonicotinoid insecticide negatively affects wild bees. *Nature* 521(7550), 77-80. https://doi.org/10.1038/nature14420.

Saillenfait, A.-M., Sabaté, J.-P., Robert, A., Cossec, B., Roudot, A.-C., Denis, F. and Burgart, M. (2013). Adverse effects of diisooctyl phthalate on the male rat reproductive development following prenatal exposure. *Reproductive Toxicology* 42, 192-202. https://doi.org/10.1016/j.reprotox.2013.09.004.

Sousa, A.C.A., Pastorinho, M.R., Takahashi, S. and Tanabe, S. (2014). History on organotin compounds, from snails to humans. *Environmental Chemistry Letters* 12(1), 117-137. https://doi.org/10.1007/s10311-013-0449-8.

Stojanoska, M.M., Milosevic, N., Milic, N. and Abenavoli, L. (2017). The influence of phthalates and bisphenol a on the obesity development and glucose metabolism disorders. *Endocrine* 55(3), 666-681. https://doi.org/10.1007/s12020-016-1158-4.

Sugino, M., Hatanaka, T., Todo, H., Mashimo, Y., Suzuki, T., Kobayashi, M., Kobayashi, M., Hosoya, O., Jinno, H., Juni, K. and Sugibayashi, K. (2017). Safety evaluation of dermal exposure to phthalates: Metabolism-dependent percutaneous absorption. *Toxicology and Applied Pharmacology* 328, 10-17. https://doi.org/10.1016/J.TAAP.2017.05.009.

Swedish Chemicals Agency (2018). Organotin compounds, 13 December. https://www.kemi.se/en/prio-start/chemicals-in-practical-use/substance-groups/organotin-compounds. Accessed 18 February 2019.

Tokar, E.J., Xu, Y. and Waalkes, M.P. (2015). Cancer induced by exposure to arsenicals in animals. In *Arsenic.* States, J.C. (ed.). Hoboken, NJ: John Wiley & Sons. Chapter 19. 439-452. https://doi.org/10.1002/9781118876992.ch19.

Transparency Market Research (2015). Solar cell films market (type - amorphous silicon, cadmium telluride, and copper indium gallium selenide; end user - residential, commercial, and industrial) - global industry analysis, size, share, growth trends, and forecast 2015-2023. https://www.transparencymarketresearch.com/solar-cell-films-market.html. Accessed 2 May 2018.

Tsvetkov, N., Samson-Robert, O., Sood, K., Patel, H.S., Malena, D.A., Gajiwala, P.H., Maciukiewicz, P., Fournier, V. and Zayed, A. (2017). Chronic exposure to neonicotinoids reduces honey bee health near corn crops. *Science* 356(6345), 1395-1397. https://doi.org/10.1126/science.aam7470.

United Nations Environment Programme (2016). *Marine Plastic Debris and Microplastics – Global Lessons and Research to Inspire Action and Guide Policy Change*. http://wedocs.unep.org/handle/20.500.11822/7720.

United States Agency for Toxic Substances and Disease Registry (2012). *Toxicological Profile for Cadmium*. https://www.atsdr.cdc.gov/toxprofiles/tp5.pdf.

United States Agency for Toxic Substances and Disease Registry (2005). Toxicological profile for tin and tin compounds. https://www.atsdr.cdc.gov/toxprofiles/tp55.pdf.

United States Agency for Toxic Substances and Disease Registry (2007). *Toxicological Profile for Arsenic*. https://www.atsdr.cdc.gov/toxprofiles/tp2.pdf.

United States Centers for Disease Control and Prevention (2017a). *Fourth National Report on Human Exposure to Environmental Chemicals: Updated Tables, Volume 1*. https://www.cdc.gov/biomonitoring/pdf/FourthReport_UpdatedTables_Volume1_Jan2017.pdf.

United States Centers for Disease Control and Prevention (2017b). Bisphenol A (BPA) factsheet, 7 April. https://www.cdc.gov/biomonitoring/BisphenolA_FactSheet.html. Accessed 20 February 2019.

United States Centers for Disease Control and Prevention (2017c). Polycyclic Aromatic Hydrocarbons (PAHs) factsheet, 7 April. https://www.cdc.gov/biomonitoring/PAHs_FactSheet.html. Accessed 18 April 2018.

United States Centers for Disease Control and Prevention (2017d). Phthalates factsheet, 7 April. https://www.cdc.gov/biomonitoring/Phthalates_FactSheet.html. Accessed 17 August 2018.

United States Centers for Disease Control and Prevention (2017e). Triclosan factsheet, 7 April. https://www.cdc.gov/biomonitoring/Triclosan_FactSheet.html. Accessed 13 June 2018.

United States Centers for Disease Control and Prevention (2018). National report on human exposure to environmental chemicals. https://www.cdc.gov/exposurereport/index.html. Accessed 17 August 2018.

United States Food and Drug Administration (2017). The microbead-free waters act: FAQs, 11 March. https://www.fda.gov/Cosmetics/GuidanceRegulation/LawsRegulations/ucm531849.htm. Accessed 25 April 2018.

United States Geological Survey (2018). *Mineral Commodity Summaries 2018*. https://minerals.usgs.gov/minerals/pubs/mcs/2018/mcs2018.pdf.

United States National Institute of Environmental Health Sciences (2014). *Arsenic*. https://www.niehs.nih.gov/health/materials/arsenic_508.pdf.

United States National Oceanic and Atmospheric Administration (2018). What are microplastics? 25 June. https://oceanservice.noaa.gov/facts/microplastics.html. Accessed 14 June 2018.

Van Cauwenberghe, L. and Janssen, C.R. (2014). Microplastics in bivalves cultured for human consumption. *Environmental Pollution* 193, 65-70. https://doi.org/10.1016/J.ENVPOL.2014.06.010.

van der Sluijs, J.P., Amaral-Rogers, V., Belzunces, L.P., Bijleveld van Lexmond, M.F.I.J., Bonmatin, J.-M., Chagnon, M., Downs, C.A., Furlan, L., Gibbons, D.W., Giorio, C., Girolami, V., Goulson, D., Kreutzweiser, D.P., Krupke, C., Liess, M., Long, E., McField, M., Mineau, P., Mitchell, E.A.D., Morrissey, C.A., Noome, D.A., Pisa, L., Settele, J., Simon-Delso, N., Stark, J.D., Tapparo, A., Van Dyck, H., van Praagh, J., Whitehorn, P.R. and Wiemers, M. (2015). Conclusions of the worldwide integrated assessment on the risks of neonicotinoids and fipronil to biodiversity and ecosystem functioning. *Environmental Science and Pollution Research* 22(1), 148-154. https://doi.org/10.1007/s11356-014-3229-5.

Ventrice, P., Ventrice, D., Russo, E. and De Sarro, G. (2013). Phthalates: European regulation, chemistry, pharmacokinetic and related toxicity. *Environmental Toxicology and Pharmacology* 36(1), 88-96. https://doi.org/10.1016/J.ETAP.2013.03.014.

Wang, C.-F. and Tian, Y. (2015). Reproductive endocrine-disrupting effects of triclosan: Population exposure, present evidence and potential mechanisms. *Environmental Pollution* 206, 195-201. https://doi.org/10.1016/J.ENVPOL.2015.07.001.

Watkins, D.J., Sánchez, B.N., Téllez-Rojo, M.M., Lee, J.M., Mercado-García, A., Blank-Goldenberg, C., Peterson, K.E. and Meeker, J.D. (2017). Phthalate and bisphenol A exposure during in utero windows of susceptibility in relation to reproductive hormones and pubertal development in girls. *Environmental Research* 159, 143-151. https://doi.org/10.1016/j.envres.2017.07.051.
Wood, T.J. and Goulson, D. (2017). The environmental risks of neonicotinoid pesticides: a review of the evidence post 2013. *Environmental Science and Pollution Research* 24(21), 17285-17325. https://doi.org/10.1007/s11356-017-9240-x.

Woodcock, B.A., Isaac, N.J.B., Bullock, J.M., Roy, D.B., Garthwaite, D.G., Crowe, A. and Pywell, R.F. (2016). Impacts of neonicotinoid use on long-term population changes in wild bees in England. *Nature Communications* 7, 1-8. https://doi.org/10.1038/ncomms12459.

Woodcock, B.A., Bullock, J.M., Shore, R.F., Heard, M.S., Pereira, M.G., Redhead, J., Ridding, L., Dean, H., Sleep, D., Henrys, P., Peyton, J., Hulmes, S., Hulmes, L., Sárospataki, M., Saure, C., Edwards, M., Genersch, E., Knäbe, S. and Pywell, R.F. (2017). Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. *Science* 356(6345), 1393-1395. https://doi.org/10.1126/science.aaa11t90.

World Energy Council (2016). *World Energy Resources: Solar*. https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Solar_2016.pdf.

World Health Organization (2018a). International Programme on Chemical Safety: ten chemicals of major public health concern. http://www.who.int/ipcs/assessment/public_health/chemicals_phc/en/. Accessed 26 September 2018.

World Health Organization (2018b). Arsenic: Key facts, 15 February. http://www.who.int/en/news-room/fact-sheets/detail/arsenic. Accessed 18 April 2018.

World Health Organization (2018c). Lead poisoning and health, 23 August. http://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health. Accessed 14 June 2018.

Zhang, L., Rana, I., Shaffer, R.M., Taioli, E. and Sheppard, L. (2019). Exposure to glyphosate-based herbicides and risk for non-hodgkin lymphoma: a meta-analysis and supporting evidence. *Mutation Research/Reviews in Mutation Research*. https://doi.org/10.1016/j.mrrev.2019.02.001.

## Chapter 6

Normile, D., (2017). International trade shifts the burden of pollution-related deaths, 29 March. *Science*. https://doi.org/10.1126/science.aal0979. Accessed 17 February 2019.

Secretariat of the Strategic Approach to International Chemicals Management (2018). *Report of the Second Meeting in the Intersessional Process to Consider the Strategic Approach and the Sound Management of Chemicals and Waste Beyond 2020*. http://www.saicm.org/Portals/12/Documents/meetings/Bureau/ICCM5B5/SAICM%20IP%202%20report%20FINAL.pdf.

Urho, N. (2018). *Options for Effective Governance of the Beyond-2020 Framework for Sound Management of Chemicals and Waste: Lessons Learned from Other Regimes*. Boston, MA: Center for Governance and Sustainability, University of Massachusetts Boston. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_14_Governance_CGS_f.pdf.

# III. Advancing and sharing chemicals management tools and approaches: taking stock, looking into the future

## About Part III

In Part II a range of initiatives by countries, international organizations and other stakeholders to achieve sound management of chemicals are described. Part III provides insights into the progress made, as well as gaps and opportunities concerning science-based approaches, tools, methodologies and instruments used in managing chemicals to protect human health and the environment. Valuable lessons have been learned over the past decades in the practical application of these approaches, tools, methodologies and instruments. In addition, opportunities have emerged to enhance their effectiveness, simplify their use, and employ them more systematically in all countries.

The order of the chapters in Part III generally follows the chemical risk assessment and risk management process. That process leads from hazard assessment to exposure assessment, risk assessment, and risk management and alternatives assessment. Later in Part III, special attention is given to chemical risk management in small and medium-sized enterprises (SMEs) and the informal sector in developing countries – including the challenges faced and opportunities to improve chemical safety in these settings.

Part III concludes with a forward-looking chapter (Chapter 8) on assessment approaches that consider a life cycle perspective and broader sustainability criteria. Throughout Part III, specific suggestions are made concerning ways that countries with limited resources could benefit from considering scientific work undertaken in other countries that have more advanced chemical management schemes.

Governments are the main drivers of the risk assessment and risk management approaches presented. However, Part III also addresses a range of work in (and results generated by) international organizations, which bring together governments and other actors, particularly industry, to identify opportunities for collaboration and foster harmonized approaches. These organizations include the World Health Organization (WHO) and the United Nations Economic Commission for Europe (UNECE), which serve as the secretariat for the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Furthermore, the Organisation for Economic Co-operation and Development (OECD) leads a range of technical work to harmonize methods and approaches that are used in its 36 member countries and in many other countries. Global risk assessment and management actions on chemicals of global concern are facilitated though a number of legally binding and soft law instruments, several of which are serviced by the United Nations Environment Programme.

## Contents

1/ Hazard assessment: progress in information generation and hazard characterization 384

2/ Exposure assessment: benefiting from internationally available resources 396

3/ Risk assessment: opportunities to improve and accelerate progress 406

4/ Risk management decision-making: making it work in all countries 419

5/ Assessment of chemical and non-chemical alternatives: focusing on solutions 435

6/ Chemical risk management in facilities and during production 453

7/ Approaches to sustainability assessment 468

References 474

# 1/ Hazard assessment: progress in information generation and hazard characterization

## Chapter Highlights

Harmonization of test methods saves resources and reduces the need for animal testing.

Important progress and efficiencies are being obtained through the use of new methodologies based on the grouping of chemicals.

Hazard classification criteria have been developed in the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). However, achieving globally harmonized hazard classifications of chemicals has proven more challenging.

Efficiencies can be obtained through global sharing and acceptance of hazard assessments undertaken at the national or regional level.

All of the actions above would result in major efficiencies for all actors concerned, but would benefit, in particular, countries with limited resources.

Chemical hazard assessment is the first stage in the risk assessment and risk management process. This chapter summarizes advances in the approaches and methods that are used to generate chemical hazard data and to assess chemical hazards globally. It also identifies gaps and points to opportunities to accelerate chemical hazard assessment.

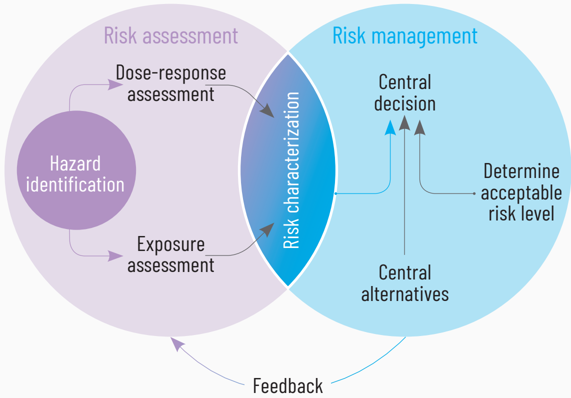
Chemical risk assessment has been described as a systematic process that is "intended to calculate or estimate the risk to a given target organism, system or (sub) population, including the identification of attendant uncertainties, following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system" (OECD 2003). It comprises four steps: hazard identification, hazard assessment (also called "hazard characterization" or "dose-response assessment"), exposure assessment, and finally risk characterization. Risk assessment is followed by risk management decision-making and by the implementation of risk management measures, if these are considered necessary.

## 1.1 Drivers for the generation of hazard information

### What are chemical hazards?

The term chemical hazard refers to the intrinsic properties of chemicals which have the potential to cause adverse effects on human health and the environment. Examples of such properties include: acute toxicity; corrosive properties; the ability to bring about allergies; long-term effects on reproduction, development and other

**Figure 1.1** From risk assessment to risk management (adapted from United States National Library of Medicine 2018, image source: Oak Ridge Associated Universities©)




systems in the human body; and persistence in environmental media. A hazard assessment is a qualitative and – where possible – quantitative description of the adverse effects of a chemical, based on generated information (American Chemical Society 2018; Swedish Chemicals Agency [KEMI] 2018). Many factors can influence the impacts of exposure to a chemical. These factors include the dose and duration of the exposure, the kinetics of the chemical in an organism, and the susceptibility of the exposed organism.

*Who generates chemical hazard information?*

Given the size of the global chemicals market and the potential of many chemicals to cause harm, there is broad consensus internationally that more hazard information is needed to allow meaningful hazard assessments to be made. National, intergovernmental, industry and other initiatives to identify chemical properties in order to carry out hazard assessment include:

- *Regulatory requirements:* In many countries a minimum set of information on new chemicals – as defined by national jurisdictions – and on priority existing chemicals already on the market is required by chemical safety

legislation. Such legislation exists, for example, in Canada (Government of Canada 2016a), the European Union (EU) (European Commission [EC] 2006; European Chemicals Agency [ECHA] n.d. a), Japan (Japan Ministry of Economy, Trade and Industry 2016) and the United States (United States Environmental Protection Agency [US EPA] 2018a; US EPA 2018b).

- *Testing of new chemicals in the development stage:* In the development stage of new chemicals, producers often use predictive methods such as quantitative structure-activity relationships (QSAR) and screening to identify hazardous properties of candidate chemicals, or to perform screening risk assessments for these chemicals' intended uses. As chemicals move from the research and development phase to production, additional testing is often performed to obtain better knowledge for use in deciding whether (and which) risk reduction measures will be needed to adequately protect workers involved in their production and use and to protect the environment (Maertens *et al*. 2014).

- *Research programmes:* Extensive testing of the mechanisms of toxicity of chemicals takes place in research programmes, for example to develop test methods for new types of substances whose impacts on human health and the environment are not yet fully understood, such as nanomaterials (US EPA 2016; Gottardo *et al.* 2017; EC 2018; OECD 2018a) or to investigate newly identified effects, as in the case of endocrine disruptors (Beronius *et al.* 2014; US EPA 2017).

### Harmonization of test methods saves resources and reduces use of animals

To support regulatory requirements in member countries of the Organisation for Economic Co-operation and Development (OECD), standardization of test methods has been identified as an important area of OECD work. This includes precise characterization of the test substance and ensures methods' reproducibility and transferability (OECD 2005). The Test Guidelines developed by the OECD are the most complete set of international standards for chemical hazard testing for regulatory purposes. They include methods to determine physical-chemical properties, ecotoxicity, fate and behaviour in the environment, and mammalian toxicity (OECD 2018b; OECD 2018c; OECD 2018d; OECD 2018e). Quality control is ensured through the OECD Principles of Good Laboratory Practice (GLP) and the GLP compliance monitoring system (OECD 2018f). The OECD Test Guidelines are continuously updated and further developed. For example, for technically challenging substances such as nanomaterials the OECD is currently working on a set of standardized Test Guidelines for, inter alia, precise characterization to enable appropriate testing and assessment of these substances (OECD 2018g).

Through international standardization and harmonization of test methods, resources needed for chemical hazard assessment can be significantly reduced: chemicals need to be tested only once, after which the results will be accepted in many other countries (OECD 2018h). The OECD's system of Mutual Acceptance of Data (whereby test results generated according to the OECD Test Guidelines and the OECD Principles of GLP are in principle accepted in 42 OECD and non-OECD countries) was already estimated in 2010 to save governments and industry about euros 150 million per year (OECD 2010). Avoiding duplication of testing also significantly reduces the use of animals in testing (OECD 2018i).

## 1.2 Test methods to identify chemical hazards are evolving rapidly

### Animal testing provides important information, but progress is being made on non-animal test methods

Chemical testing has traditionally been carried out on animals (e.g. rats, mice and fish). Through the use of laboratory animals, insights can be obtained into the toxicological effects a chemical could have on humans or wildlife. For certain more complicated toxicological endpoints, such as carcinogenicity and effects on the reproductive system, this type of testing can be costly, requires large numbers of animals and raises ethical concerns. While such testing may be required by statute, it is usually conducted for chemicals which are a priority due to their high production volumes, their wide use, or the expectation that they have hazardous properties of particular concern (e.g. are carcinogenic).

Reducing, refining and replacing test methods that use laboratory animals has been a priority in many countries for many years. In particular, since the publication of the report *Toxicity Testing in the 21st Century: A Vision and a Strategy* (United States National Academy of Sciences 2007), governments have increased their efforts to move towards the adoption of alternative test methods such as systems using cell cultures (*in vitro* methods) instead of animals *(in vivo* methods) (Krewski *et al*. 2010). The most recent developments in this field include high-throughput screening and toxicogenomics and RNA sequencing methodologies. An example of work being carried out is the US EPA's ToxCast programme, which includes publicly available high-throughput toxicity data on thousands of chemicals (US EPA 2018c). High-throughput screening results are especially useful in setting priorities for further work to investigate hazards. Another approach with significant potential to replace animal testing is *in vitro* embryonic stem cell research (Colaianna *et al.* 2017; Cynober 2018).

Guidance on the use of non-animal testing approaches under relevant European legislation has been developed by the ECHA (ECHA 2017a; ECHA 2017b; ECHA 2017c). In the United States new approaches and alternative methods for use in a regulatory context are developed and evaluated (US EPA 2018d; United States Interagency Coordinating Committee on the Validation of Alternative Methods 2018). Many of the new testing methods are not direct replacements for *in vivo* tests. Instead, they require countries to accept different approaches to hazard identification for regulatory purposes (see also section 1.3 below). Considerable progress has been made in the international development of methods that do not require the use of animals in testing. However, it is expected that this (often expensive) type of testing will continue to be needed in the coming decade, particularly for long-term toxicity endpoints.

© Kate Holt/AusAID, Scientists work in a laboratory at the International Livestock Research Institute in Nairobi, Kenya. Australia provides funding to the Institute through the Australian Centre for International Agricultural Research (ACIAR), to improve African food security CC BY 2.0

### What are current opportunities for global acceptance of test data?

As discussed in Part II, a number of countries are establishing regulatory frameworks or upgrading frameworks already in place in order to advance sound chemicals management – including through provisions concerning data requirements. These initiatives often focus on industrial chemicals, as well as on consumer uses of chemicals which are not regulated elsewhere. Examples of regulatory initiatives that involve requests for data submissions for a large number of chemicals include those in China (initiated in 2003 and amended in 2009) (Chemical Inspection and Regulation Service [CIRS] 2017; Lexology 2018), the Republic of Korea (CIRS 2012a; ChemSafetyPro 2017; ChemSafetyPro 2018; He 2019) and Turkey (CIRS 2012b; SGS 2017). As part of these initiatives, countries usually request data from both producers and importers and may therefore ask for testing.

Hazards are intrinsic chemical properties which are the same in all countries. Global acceptance of test data is, in principle, possible and desirable provided there is full transparency concerning the test methods used and the limitations of these methods. Wide acceptance of test data could provide efficiency gains and make resources available for testing more chemicals than is currently possible. Any country that requires (or plans to require) the generation of data by chemical producers and importers for hazard assessment and risk assessment could therefore consider joining the OECD's system of Mutual Acceptance of Data, which considerably reduces costs for governments and industry (see section 1.1 above). In the context of the sound management of chemicals and waste beyond 2020, ways to promote global acceptance of data on chemicals' hazards might be agreed by countries.

## 1.3 New approaches are accelerating hazard assessment

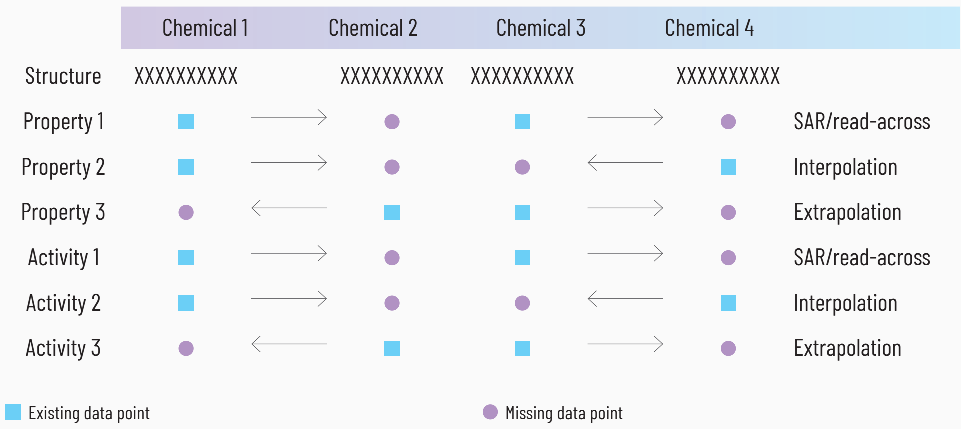
### Encouraging progress is being made through emerging approaches, e.g. grouping, and read-across

New Approach Methodologies and their integration in regulatory settings are being widely discussed because of their potential to complement traditional approaches (ECHA 2016a; Environment and Climate Change Canada 2016; US EPA 2018e) (see also Part III, Ch. 3). In addition to the growing use of *in vitro* (non-animal) testing methods, *non-testing* methods are increasingly used to obtain data on chemical hazards. This may involve grouping chemicals based on similar properties and then filling data gaps through read-across (Figure 1.2) (Berggren *et al.* 2015). Furthermore, a joint US EPA, Government of Canada and ECHA initiative on Accelerating the Pace of Chemical Risk Assessment (APCRA) aims to develop a series of joint case studies which could help increase the use of New Approach Methodologies for chemical prioritization, screening and quantitative risk assessment (ECHA and US EPA 2016).

ECHA reported in 2017 that read-across was the most common alternative method used by industry to comply with Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) hazard information requirements (ECHA 2017b). Assessments under Canada's Chemicals Management Plan also commonly use read-across (Government of Canada 2017). For grouping challenging substances such as nanomaterials, progress has been made in using read-across (ECHA 2017c).

The development of computer tools such as the OECD's QSAR Toolbox for Grouping Chemicals into Categories (OECD 2007; Dimitrov *et al*. 2016; OECD 2018j) or the European Chemical Industry Council's AMBIT (Jeliazkova *et al.* 2016; European Chemical Industry Council Long-Range Research Initiative 2017) exemplify the trend to use read-across for chemical hazard assessment. The QSAR Toolbox helps users apply read-across by identifying relevant structural characteristics and the potential mechanisms or mode of

**Figure 1.2** Graphical representation of a chemical category and some approaches for filling data gaps (adapted from OECD 2014a, p. 14)




In a group of chemicals whose physical-chemical and human health and/or ecotoxicological properties and/or environmental fate properties are likely to be similar, or to follow a regular pattern (usually as a result of structural similarity), not all of these chemicals need to be tested for all properties. Above is a representation of some approaches that can be used to fill data gaps: SAR (structure-activity relationship)/read-across, interpolation and extrapolation.

action of a target chemical. It also helps identify other chemicals that have the same structural characteristics and/or mechanism or mode of action.

### A more holistic approach to information generation is needed

Despite the progress already made, a more holistic approach to testing across national jurisdictions could involve defining categories and jointly identifying priority chemicals for testing. The results could be used to inform a better understanding of the properties of many other chemicals in the same category (US EPA 2010; Government of Canada 2016b). Further integration of information generated through toxicity and ecotoxicity testing could also help achieve a more holistic approach to interpreting hazard information.

The OECD's Mutual Acceptance of Data system has been effective in ensuring wider acceptance of test data. However, efforts to bring about the acceptance of conclusions on hazard identification that use different types of information (such as *in silico* or computational data) have not been as successful. One reason could be that regulators are not yet fully convinced of the reliability of the newer methods since insights into the validity of the results have not yet been accepted internationally. As science advances, growing confidence in these new methods could nurture broader regulatory acceptance. In the context of sound management of chemicals and waste beyond 2020, agreements on international standardization and validation efforts could widen the availability of information on hazard properties and promote wider (if gradual) regulatory acceptance globally, leading to significant efficiencies.

### A new hazard assessment paradigm focusing on Adverse Outcome Pathways is being developed

As a possible bridge towards 21st century toxicity testing (see section 1.1 above), the concept of Adverse Outcome Pathways (AOPs) is gaining momentum and is being investigated. An AOP is "a logical sequence of key events triggered by chemical exposure and occurring at the molecular, cellular, organ, whole organism or population level" (OECD 2017). An AOP investigation involves studying an interaction at a molecular target (a Molecular Initiating Event, or MIE), which then signals events within a cell or tissue and leads to an adverse outcome. The adverse outcome can occur at any biological level of organization. It could have regulatory significance if it corresponds to a protection goal or endpoint in a regulatory guideline test. Interactions among the levels within an AOP may be causal, mechanistic, inferential or correlation-based. By gathering mechanistic information relevant to specific adverse outcomes, regulators might be able to identify key events that are predictive of the adverse outcome, and for which (*in vitro*) test methods can be developed. While experience with the use of AOPs is limited – and there is still a significant gap between AOP-based approaches and hazard assessment that is based on traditional test data – AOPs are already particularly helpful for obtaining in-depth insights into the mechanism of the toxicity exhibited by groups of chemicals.

Information generated through an AOP can be used, for example, to:

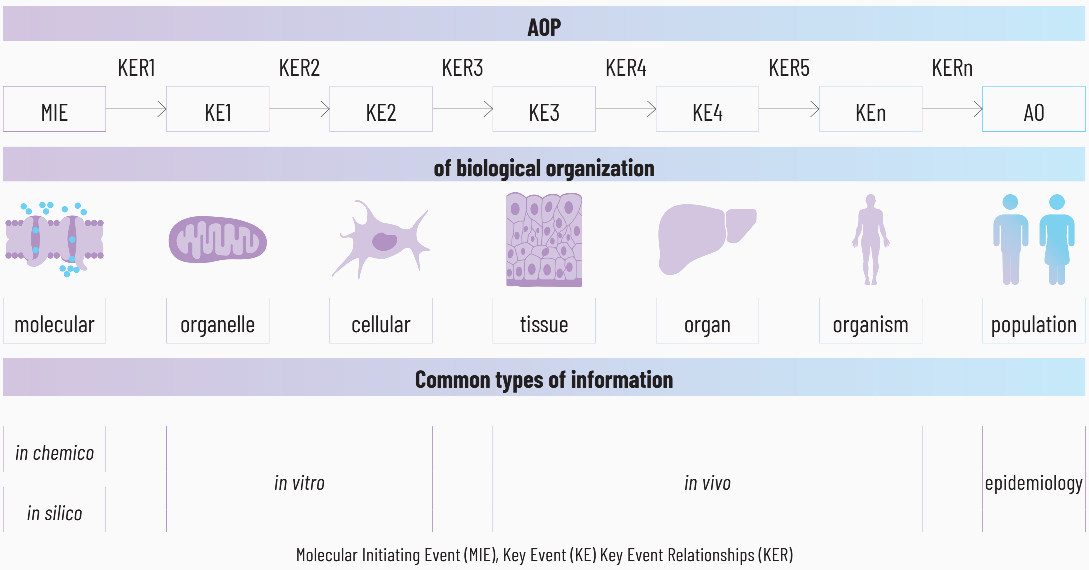
- interpret results from non-standardized test methods;
- group chemicals into toxicologically meaningful categories;
- develop testing strategies; or
- select test methods that can be standardized and harmonized.

Figure 1.3 illustrates the AOP concept within an Integrated Approach to Testing and Assessment (IATA). This approach has already been successfully piloted for the hazard endpoint of skin sensitization. OECD Test Guidelines have been developed for all relevant key events in the AOP (OECD 2014b). The success of this approach for other endpoints will depend on the availability of scientific knowledge about the mechanism of action of chemicals. To further strengthen the scientific robustness of predictions based on grouping and read-across, regulatory authorities are using the AOP concept by, for example, grouping chemicals that are predicted to trigger the same AOP. As a single AOP is unlikely to capture all events of potential regulatory significance, AOP networks (based on AOPs that share at least one common element) will help provide further representation of pathways that lead to adverse outcomes (Delrue *et al*. 2016).

### Opportunities to accelerate chemical hazard assessment and fill knowledge gaps

Many countries are actively engaged in assessing the hazards and risks of priority chemicals on

**Figure 1.3** Testing and assessment based on the Adverse Outcome Pathway (AOP) concept (adapted from Vinken *et al.* 2017, p. 3699)



their markets, as called for by the 2020 goal (see Part II). Nevertheless, the generation of new and robust test results remains quite limited. The ECHA has reported that, overall, 11 per cent of total REACH information requirements were generated by new experimental studies performed on vertebrate animals (ECHA 2017d). Given that alternative methods are still evolving, authorities are having difficulty assessing the hazards of a number of chemicals, including those that potentially have CMR (carcinogenic, mutagenic or reprotoxic) properties based on such methods.

A study by the German Federal Institute for Risk Assessment found that for chemicals produced in volumes above 1,000 tonnes which were registered under REACH, an average of 39 per cent were compliant with the information requirements for eight toxicological endpoints, ranging from 19 per cent for developmental toxicity to 56 per cent for biotic degradation. The rest of the dossiers were non-compliant or did not allow final conclusions to be made on the dossier due to methodological limitations (ECHA 2017e). Better compliance with information requirements would obviously help accelerate hazard assessments.

The ECHA estimated that of 4,450 substances manufactured or imported above 100 tonnes/year registered under REACH, about 3,000 could not be categorized as either low or high priority for in-depth evaluation, partly due to lack of hazard data, but also partly due to insufficient use information to allow this type of categorization (ECHA 2016a). In the recently completed registration of existing chemicals in the EU, 5,900 chemicals were registered in the 1-10 tonnes/year range and 4,000 in the 10-100 tonnes/year range. These chemicals still need to be considered by the ECHA.

Limited generation of new test results also has repercussions on the use of grouping and read-across. These techniques rely on the presence of high-quality experimental results for at least some members of a group or category of chemicals. In the absence of adequate experimental results for close analogues, this approach cannot be applied. That may be especially problematic in the case of low-volume production chemicals, for which most jurisdictions do not require test data. In such cases information for classification and labelling may also be derived from non-test methods, as is the case for new chemicals under the Toxic Substances Control Act (TSCA) in the United States (US EPA 2017).

## 1.4 Achieving globally harmonized classifications of chemicals is challenging, but valuable

### Globally harmonized criteria are accepted, but how feasible are globally accepted classifications of chemicals?

The development of the Globally Harmonized System for Classification and Labelling of Chemicals (GHS) and its implementation by a

**Table 1.1** Health hazards and environmental hazards – classes for global hazard classification (Derived from UN 2017)

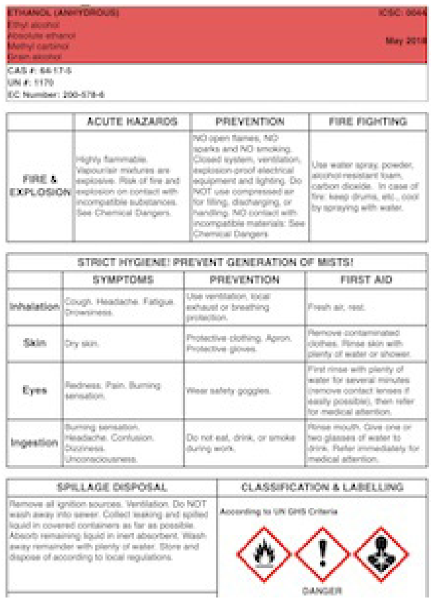
| Health hazards | Environmental hazards |
|---|---|
| › Acute toxicity | › Hazardous to the aquatic environment |
| › Skin corrosion/irritation | › Hazardous to the ozone layer |
| › Serious eye damage/eye irritation | |
| › Respiratory or skin sensitization | |
| › Germ cell mutagenicity | |
| › Carcinogenicity | |
| › Reproductive toxicity | |
| › Specific target organ toxicity-single exposure | |
| › Specific target organism-repeated exposure | |
| › Aspiration hazards | |

growing number of countries has been one of the successes in the field of chemical safety during the last 20 years (Persson *et al.* 2017; UNECE n.d.). Globally harmonized classification criteria have been developed for physical, health and environmental hazards. Table 1.1 shows the specific health and environmental hazards covered by the GHS (United Nations [UN] 2017). Despite the many hazards covered already, work could be undertaken to increase the number of hazard criteria, particularly with respect to environmental hazards and endocrine disruption.

While the GHS has established harmonized criteria for hazard classification, companies – and, in some cases, governments – classify chemicals individually. This may result in different classifications of the same chemical due to different interpretations of available test results. Not only can different classifications of the same chemical create confusion, but such parallel classifications may waste resources. Although it might be difficult to achieve a globally harmonized list of classified chemicals, work is ongoing to explore the potential development of such a list in a cost-effective manner (OECD 2016).

A pilot classification project has been carried out for three substances, each sponsored by a country or agency (OECD 2016). The sponsors spent an average of 38 days drafting and updating the substance classification proposals. Reviewers then spent another five days checking them. The report from the pilot exercise demonstrated that the process is feasible; however, it would require sustained commitment of time and resources by countries and other interested parties.

In view of the resources needed to develop a global list of chemicals with harmonized classifications, agreement has not yet been reached on whether to begin this initiative. Such a list of classified substances would not only create consistency, but would significantly benefit countries with few resources. In the absence of such a list, the work of the International Labour Organization (ILO) and the WHO to produce International Chemical Safety Cards (ICSC) in line with the GHS is very useful (WHO 2019). To date, more than 1,700 of these cards are available in English, while national institutions translate them into their respective languages (ILO 2018). In addition, the EU has already agreed on harmonized classifications for chemicals using GHS criteria. These national or regional lists of classified chemicals can be consulted by countries with limited resources which are committed to implementing the GHS.



ETHANOL (ANHYDROUS) — ICSC: 0044
Ethyl alcohol
Absolute ethanol
Methyl carbinol
Grain alcohol
May 2018
CAS #: 64-17-5
UN #: 1170
EC Number: 200-578-6

| | ACUTE HAZARDS | PREVENTION | FIRE FIGHTING |
|---|---|---|---|
| FIRE & EXPLOSION | Highly flammable. Vapour/air mixtures are explosive. Risk of fire and explosion on contact with incompatible substances. See Chemical Dangers. | NO open flames, NO sparks and NO smoking. Closed system, ventilation, explosion-proof electrical equipment and lighting. Do NOT use compressed air for filling, discharging, or handling. NO contact with incompatible materials: See Chemical Dangers. | Use water spray, powder, alcohol-resistant foam, carbon dioxide. In case of fire: keep drums, etc., cool by spraying with water. |

STRICT HYGIENE! PREVENT GENERATION OF MISTS!

| | SYMPTOMS | PREVENTION | FIRST AID |
|---|---|---|---|
| Inhalation | Cough. Headache. Fatigue. Drowsiness. | Use ventilation, local exhaust or breathing protection. | Fresh air, rest. |
| Skin | Dry skin. | Protective clothing. Apron. Protective gloves. | Remove contaminated clothes. Rinse skin with plenty of water or shower. |
| Eyes | Redness. Pain. Burning sensation. | Wear safety goggles. | First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then refer for medical attention. |
| Ingestion | Burning sensation. Headache. Confusion. Dizziness. Unconsciousness. | Do not eat, drink, or smoke during work. | Rinse mouth. Give one or two glasses of water to drink. Refer immediately for medical attention. |

| SPILLAGE DISPOSAL | CLASSIFICATION & LABELLING |
|---|---|
| Remove all ignition sources. Ventilation. Do NOT wash away into sewer. Collect leaking and spilled liquid in covered containers as far as possible. Absorb remaining liquid in inert absorbent. Wash away remainder with plenty of water. Store and dispose of according to local regulations. | According to UN GHS Criteria<br>DANGER |

## 1.5 Global relevance of the growing knowledge about chemical hazards

### Improved knowledge-sharing

Owing to the internet and other information technology, the availability and accessibility of data for use in hazard and risk assessment has greatly improved in the last two decades. A number of portals facilitate locating relevant data (Wexler *et al*. 2016) relevant for classification and labelling, as well as results already obtained and documented in countries and by intergovernmental organizations. While the databases include a wealth of information, users may still need to interpret the data and derive the resulting hazard characterisations and hazard classifications. The eChemPortal (Box 1.1) is an example of a portal featuring full hazard assessments and/or classifications with the underlying data and justifications.

An example of a more specialized portal developed by the ECHA and the OECD is the International Uniform Chemical Information

**Box 1.1** The eChemPortal (OECD n.d.)

The eChemPortal (www.echemportal.org) is a global portal providing information on chemical substances. Managed by the OECD, it is an example of the recently developed internet portals that provide easy access to information relevant for chemical safety and regulatory decision-making. eChem allows users to search for information on individual chemicals or to query by property (e.g. chemicals on which a positive test result for carcinogenicity is available). As of 2017, 34 data sources were participating in this initiative and 13 of them had GHS classification information.


Database (IUCLID). IUCLID is a software application which allows users to record, store, maintain and exchange data on the intrinsic and hazard properties of chemical substances. It is an important software application for regulatory bodies and the chemical industry, which use it to implement various regulatory programmes (ECHA and OECD 2018). The ECHA also maintains databases on the safe use of chemicals including nanomaterials ("Search for Chemicals": ECHA n.d. b). These databases combine information submitted by industry with that gathered and generated by the ECHA, competent authorities in EU Member States and other regulators. Information which is (or will be) available from the ECHA is described in Box 1.2.

**Box 1.2** **The European Chemicals Agency's longer-term vision for improving access to information (ECHA 2016b)**

In years to come the European Chemicals Agency (ECHA) will be taking on new tasks, such as establishing a new central database, by the end of 2019, with information available to waste treatment operators and consumers about substances of concern (ECHA 2018). It may also host the European Chemicals Legislation Finder (EUCLEF), bringing together information on European Community legislation regulating chemicals. This will further increase the volume of data held by the ECHA in its databases.

In this context, the ECHA has a long-term vision of increasing and simplifying access to the vast scientific data collections it holds and encouraging the reuse of these data (ECHA 2016b). As part of that effort, it is currently preparing an initiative to explore opportunities for a common data platform, together with the European Food Safety Authority (EFSA) and with the support of the European Parliament. This initiative aims to include a registry of toxicological studies for chemical substances and regulated products performed by industry (which could also be fed by third parties such as academic institutions) in order to serve as an open repository for research and scientific data. Such a platform could provide data analytics, predictive toxicology (which could avoid animal testing), better environmental monitoring, better study design, the development of artificial intelligence, and machine learning applications.

### Opportunities for mutual acceptance of hazard assessments

The elaboration of chemical hazard assessments is resource-intensive. While there is a system in place for countries' acceptance of test results generated in other countries, there is currently no agreed international understanding on acceptance of the outcome of a hazard assessment performed in other countries. Such a system could greatly reduce the resources needed by national regulators (e.g. for classification and labelling). Companies and government agencies, especially in countries with limited resources, would benefit from the public availability of these assessments, particularly if they were well-documented (ECHA n.d. c).

The Industrial Chemicals Bill introduced in Australia in 2017 allows regulatory decisions to be taken based on the hazard assessment of a "trusted international body". Hazard assessment schemes in Canada and the EU are listed explicitly, while other bodies could potentially be added (Parliament of the Commonwealth of Australia 2017). The development of internationally harmonized criteria for what constitutes a "trusted international body" or a "trusted body" would increase the reuse of existing assessments. Alternatively, countries that need a hazard assessment (combined with exposure information) to support national decision-making could use results generated in several other countries if the hazard assessments have similar outcomes. In light of these opportunities, wider acceptance of hazard assessments could be a topic to examine in the context of sound management of chemicals and waste beyond 2020.

## 1.6 Potential measures to further advance hazard assessment

Harmonized methodologies for mutual acceptance of chemical hazard test data, standardization in regard to accepting test results, and a global list of hazard classifications would result in major efficiencies for all actors concerned. This harmonization would benefit, in particular, countries with limited resources. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance hazard assessment:

- Accelerate the generation of more comprehensive information about the intrinsic hazards and properties of chemical substances and make this information publicly available.

- Continue to work towards achieving wider international acceptance of chemical hazard test data, particularly with a view to animal welfare.
- Continue to work towards global agreement on standardization and validation efforts in regard to accepting chemical hazard data estimation results, as well as with a view to animal welfare.
- Further explore new approaches to fill data gaps and scale up the use of portals to facilitate the availability and accessibility of hazard data.
- Accelerate development of the concept of Adverse Outcome Pathways (AOPs) to support hazard assessment.
- Develop new GHS criteria (e.g. for further environmental hazards, endocrine disruption).
- Continue to explore possibilities to develop a globally harmonized list of classified chemicals based on the GHS hazard classification criteria.

# 2/ Exposure assessment: benefiting from internationally available resources

## Chapter Highlights

Modelling-based approaches have greatly enhanced knowledge about the distribution of chemicals in the environment and exposure situations.

National, regional and other contexts can play a role in determining levels of exposure.

Exposure scenarios and models are available for a range of situations. They can provide a generic basis for human and environmental exposure assessments, thus saving resources.

Wider awareness of available generic exposure assessment methods and models will help obtain insights into local human and environmental chemical exposure.

Advances are being made with respect to methods to quantify exposures from products. However, more data on product ingredients and more research are needed in this field.

Further work is needed to elucidate aggregate exposures to the same chemical, across sources, and cumulative exposures across chemicals.

Exposure assessment is context-specific, yet it may benefit from work done in other contexts or countries. This chapter summarizes state-of-the-art knowledge, methods and resources relevant for determining levels of exposure of humans and environmental media. While the national and regional specificities of the exposure context are recognized, generic exposure scenarios which could be useful in exposure assessment are highlighted. These scenarios may be particularly useful in countries that have limited resources to devote to chemicals management.

## 2.1 Understanding exposure to chemicals has greatly improved

### Exposure of workers, consumers and the environment

Exposure to chemicals takes place in many situations. It may occur through food consumption, product use, uptakes indoors and outdoors, and at the workplace. The magnitude, frequency and duration of exposure to a chemical – or to several chemicals – can be measured or estimated, along with the number and characteristics of the individuals or population exposed. For certain categories of chemicals (e.g. pharmaceutical active ingredients, food additives, cosmetics, and pesticides, including biocides) the doses recommended to be applied in their normal use are often determined and known in advance. Therefore, the assessment information available is usually more precise than for industrial chemicals. In the case of a pesticide active ingredient, for example, it is possible to examine the frequency, timing and levels of contact of workers under particular conditions of use, assuming that recommended practices are followed (US EPA 2017a). In the case of industrial chemicals and chemicals in products, lack of information on actual uses may impede drawing conclusions about the assessment of priorities and risks.

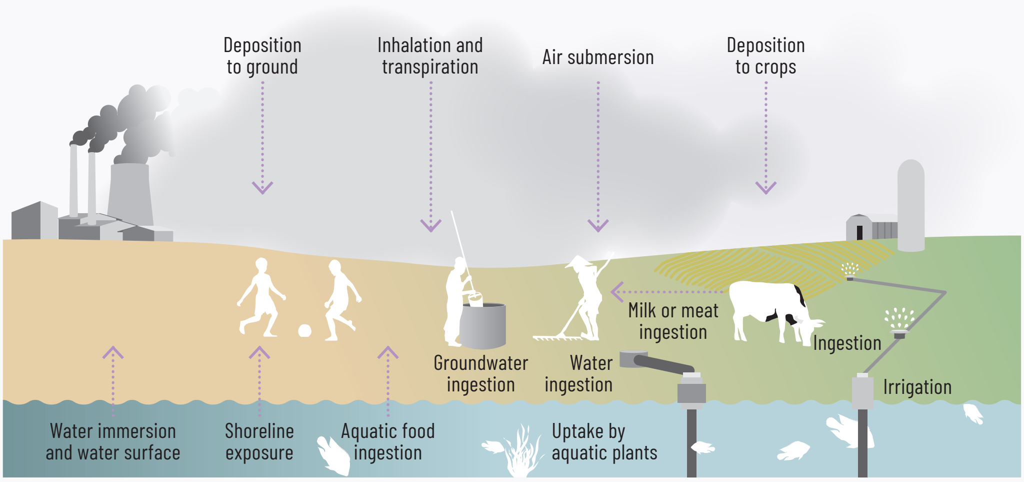
Ideally, an exposure assessment should describe sources, routes, pathways, and the uncertainty in the assessment (WHO 2004). In the assessment of human exposure many different aspects require specific consideration: the exposure route (inhalation, ingestion, dermal); the subjects of exposure (workers, the general population/ consumers, including vulnerable groups, and ecosystems); and the media which can give rise to exposure (air, water and sediment, soil and dust, food aquatic biota, consumer products).

Exposure can also occur through a combination of routes and media. The figure in Box 2.1 shows human exposure to chemicals through different environmental pathways. Besides exposure via environmental pathways, the human population can be exposed through products and indoor air emissions. In exposure assessments special attention needs to be paid to vulnerable categories such as foetuses; infants and children; women of childbearing age; pregnant and lactating women; and older adults (US EPA 2017a). The specific method used to measure or estimate exposure will depend on factors such as the purpose of the assessment and the quality and quantity of the data required (US EPA 2017b). Exposure assessments will not necessarily be relevant in all other countries or contexts. For example, conditions of pesticide use differ between and within countries.

## Measurement-based approaches are valuable, but not always possible

Measuring and monitoring the presence of a chemical in humans (human biomonitoring) or in environmental media (environmental monitoring) is one way to determine levels of exposure. Environmental monitoring is usually carried out to define the current state of the environment (e.g. when a problem related to a

**Box 2.1** Human exposure to chemicals – environmental pathways (adapted from Faustman and Omenn 2013, p. 138)




Republished with permission of McGraw-Hill Education; permission conveyed through Copyright Clearance Center, Inc.

In environmental exposure assessment, concentrations in water, sediment, soil and air are often determined (measured or calculated) in order to obtain insights into exposures of environmental species. Photodegradation, biodegradation and bioaccumulation are important factors that should also be taken into consideration. Geographic variability caused by differences in abiotic conditions such as climate, hydrology, geology and biotic conditions (e.g. differences in ecosystem structures and functions) can also influence the outcomes of environmental exposure assessments.

specific chemical is suspected) and/or to establish trends in environmental concentrations (e.g. to measure compliance with restrictions imposed on releases).

In order to determine environmental exposure, many methods exist to measure concentrations in air, water, soil and solid waste (US EPA 2017c). Such chemical analyses are usually carried out on samples taken at specific locations and times. The measured concentrations can therefore reflect variations in space and time. Measurements always need to be considered in the context of knowledge about the process leading to exposure, which could mean complicated and resource-intensive follow-up to obtain additional information. Nevertheless, provided the monitoring conditions are well-documented, information obtained through monitoring programmes can be helpful in making environmental exposure assessments (OECD 2013).

Biomonitoring is a method by which concentrations of naturally occurring and synthetic chemicals are measured in body fluids (e.g. blood, urine and breast milk) or tissue (e.g. hair, nails, fat and bone) (Box 2.2). This allows identification of the extent to which certain chemicals have entered the body and, in the case of regular measurements, how exposure may change over time. Methods that use pooled blood and urine samples to identify the most prevalent chemicals of concern in sub-populations at risk, such as children, also exist. Combining multiple individual specimens into a single sample can be a cost-effective way to monitor exposures and trends and to identify highly exposed sub-populations (Aylward *et al.* 2014; Heffernan *et al.* 2014; Heffernan *et al.* 2015). Biomonitoring can therefore provide precise information on the total internal exposure of an individual at a given time, as it adds together exposure from multiple sources and routes (e.g. air, water, food), thus also providing information on inter-individual variability and vulnerability.

In the occupational setting, according to the ILO Code of Practice, employers should monitor and

**Box 2.2 Programmes to monitor chemicals in humans and the environment**

A number of biomonitoring programmes exist. In the United States, the National Health and Nutrition Examination Survey (NHANES) is a survey research programme which aims to assess the health and nutritional status of adults and children in that country and track changes over time (United States Centers for Disease Control and Prevention [US CDC] 2018a). Much information on human exposure to environmental contaminants in the United States is made available by the Centers for Disease Control and Prevention (US CDC 2018b). As part of the Canadian Health Measures Survey (CHMS), levels of certain chemicals in the blood and urine of the population are measured (Government of Canada 2018). In the EU the Human Biomonitoring for Europe (HBM4EU) programme coordinates, advances and harmonizes human biomonitoring in Europe (Becker *et al*. 2014). This programme is expected to provide better evidence of the actual exposure of citizens to chemicals, and possible health effects, than is currently available, with a view to support policymaking (HBM4EU 2018).

The European Commission's Information Platform for Chemical Monitoring (IPChem) is a reference access point for searching, accessing and retrieving chemical occurrence data collected and managed in Europe. It has been developed to fill the knowledge gap on chemical exposure and its burden on health and the environment. IPChem is structured into four modules, according to the chemical monitoring data categorization: Environmental Monitoring, Human Bio-Monitoring, Food and Feed, and Products and Indoor Air (EC 2018). In addition, scientists and stakeholders from 35 institutions in 27 European countries are working within a human biomonitoring framework, the Consortium to Perform Human Biomonitoring on a European Scale (COPHES) (COPHES 2016).

The Stockholm Convention has put in place sustainable, harmonized and comparable human biomonitoring activities through collaboration with the United Nations Environment Programme (UNEP) and the WHO. A report on the results of a global survey on concentrations in human milk of persistent organic pollutants (POPs) was published in 2013 (UNEP and WHO 2013 and is being updated to include newly listed POPs.).

record the exposure of workers to hazardous chemicals to ensure their health and safety (ILO 1993; ILO 2004). They should also ensure that workers are not exposed to chemicals to an extent that exceeds exposure limits or other exposure criteria for the evaluation and control of the working environment. Based on monitoring data, employers should assess workers' exposure to hazardous chemicals and provide these data to the workers. These ILO requirements have been implemented in many countries (ILO 2011). This means many countries will have information about levels of exposure to a number of chemicals for a variety of occupations. The outcomes of these measurements of exposure can be of use in carrying out more generic exposure assessments.

Measurements-based approaches may be used to assess occupational exposures to chemicals throughout the supply chain of products. Such research reveals that the main exposures may occur at the intermediary stages of product manufacturing (Kijko *et al.* 2015; Kijko, Jolliet and Margni 2016). For example, in a study on occupational exposure associated with an office lounge seat, the greatest occupational exposure occurred during production of the plastic materials and resin, rather than during manufacturing of the seat or in the chemical industry (Kijko, Jolliet and Margni 2016).

Representative and reliable monitoring data are available for only a small number of industrial chemicals. Lack of measured data therefore does not mean there is a lack of exposure. Alternatively, exposure modelling and release estimation methods are widely used to obtain insights into exposure scenarios. Work process-based approaches consider potential impacts on worker health as a ratio of reported work-related morbidity and mortality to the output of industrial processes (Scanlon *et al*. 2015). In using these methods, it needs to be acknowledged that the conditions of use of a chemical can be vastly different and can be more dangerous in developing countries than in developed ones, while developing countries usually lack the resources to carry out full exposure assessments.

## National and regional specificities need to be recognized

While hazard is an intrinsic property of a chemical, exposure varies widely according to, for example, process conditions, the formulation of the product used and socio-economic conditions. With respect to environmental exposure, local aspects such as climate, average temperatures or water conditions can be significant. Given the variety of specific situations, conditions and/or purposes for which exposure assessments

may be carried out, the results of exposure assessments cannot be directly translated from one country or region to another. If conditions are similar, however, exposure scenarios produced in some countries may provide generic insights for the conduct of exposure assessments in similar contexts.

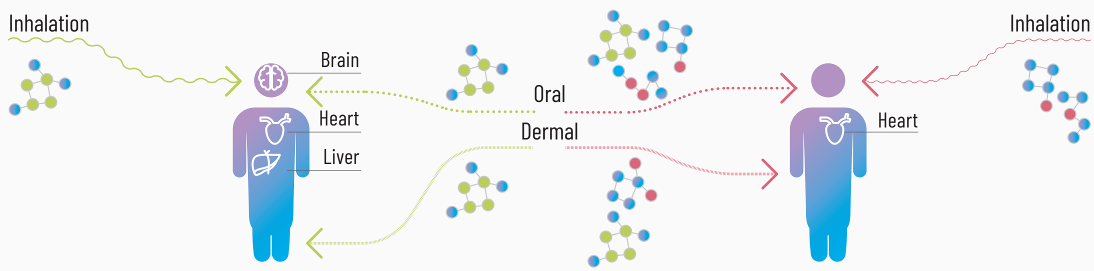
One tool for obtaining valuable information on local emissions of selected chemicals is a Pollutant Release and Transfer Register (PRTR). Under PRTR systems, point source emitters such as industrial facilities are required to report the quantities of chemical releases. These are then made available in publicly accessible databases or inventories. Emissions can be measured or estimated with the help of a wide array of available techniques (e.g. use of emission factors). Such information, in combination with effects indications, can help identify possible exposures and risks. Companies also use PRTR data to identify opportunities to improve efficiencies and reduce waste (OECD 2018a; UNECE 2018; United Nations Institute for Training and Research [UNITAR] 2018). Some PRTRs cover non-point or diffuse sources (e.g. mobile sources). The possibility of including chemical releases from products has been studied, and these releases are included to a certain extent in some countries (Nordic Council of Ministers 2006; OECD 2017).

### Understanding aggregate and cumulative exposure to chemicals is challenging

In daily life humans are rarely exposed to a single pollutant from a single source. Instead, they are exposed to a multitude of distinct organic and inorganic chemical substances found in indoor and outdoor environments (UNEP 2017; Gligorovski and Abbatt 2018). Each of these substances is associated with a variety of sources along product life cycles and following various exposure pathways, including those that contribute to inhalation, ingestion and dermal exposures. Likewise, ecosystems around the world are exposed to releases of numerous industrial and agricultural chemicals, either intentionally (e.g. pesticides) or unintentionally (e.g. pharmaceuticals). The cumulative exposure of ecosystems to the mixture of chemicals entering the environment has been identified as one of the five main pressures negatively affecting biodiversity (Secretariat of the Convention on Biological Diversity 2010). How this chemical “cocktail” interferes with human health, and how it interacts with organisms and the environment, is still largely unknown.

Single-chemical assessments may fail to adequately account for potential synergistic or antagonistic effects of chemical mixtures in humans and ecosystems. Aggregate exposure

**Figure 2.1** Aggregate (left) and cumulative (right) exposure (adapted from US EPA 2017d)




Aggregate exposure assessment considers combined exposures to a single stressor across multiple routes and multiple pathways. Cumulative exposure assessment generally evaluates combined exposure to multiple stressors via multiple exposure pathways that affect a single biological target.

across sources for the same chemical and cumulative exposure across chemicals (Figure 2.1) are therefore receiving increasing attention, along with the assessment of associated risks. Efforts to address the combined effect of chemical mixtures, such as multi-substance effect indicators for freshwater ecosystems (Posthuma *et al.* 2016), are under way. However, scientists are just beginning to derive principles that allow broader consideration of cumulative exposures and related mixture toxicity effects in humans and ecosystems (Altenburger *et al.* 2013).

To advance aggregate and cumulative exposure assessment, a number of research advances need to be made. First, systematic production and use of high-throughput exposure data (Cohen Hubal *et al.* 2010; Wambaugh *et al.* 2013) are required in order to feed complex exposure models. Second, consistent and mass balance-based integration of exposure pathways and indoor-outdoor environments in frameworks based on strictly comparative metrics is essential to systematically identify exposure hotspots and focus higher-tier assessments (Fantke *et al.* 2016). Third, mechanisms are required that support the integration of global data and tools to foster our understanding of the complexity of exposure through exposome research, which takes into account exposure to exogenous chemicals as well as endogenous chemicals that may be affected as a consequence of exogenous influences (Escher *et al.* 2017). Finally, better linking of exposure outcomes to multi-stressor toxicity information is needed to capture important correlations between chemicals, pathways and effects.

## 2.2 How can exposure be better quantified?

### A stepwise process to cover exposure throughout the life cycle

To better quantify the totality of exposures, especially when resources are limited, it is useful to focus on several steps in the assessment process:

- Obtain information about the different uses, and quantities thereof, within different regulatory contexts.
- Define chemical usage scenarios and the masses emitted during manufacturing (that is, at the workplace) and other life cycle stages.
- Identify the fate and exposure processes that result in transfers to biota and to humans.
- Determine exposure to the chemicals in consumer products.

### Use of generic exposure scenarios is valuable for industrial chemicals

It is not always necessary to carry out resource-intensive measurements to obtain insights into exposure levels. To help countries with limited resources derive such insights, valuable information is available for understanding exposure scenarios. An exposure scenario has been defined as "a combination of facts, assumptions, and interferences that define a discrete situation where potential exposures may occur. These may include the source, the exposed population, the time frame of exposure, microenvironment(s), and the activities. Scenarios are often created to aid exposure assessors in estimating exposure" (WHO 2004). In the EU's REACH Regulation an exposure scenario refers to an identified use, or group of similar identified uses, such as formulation, processing or production of an article (ECHA 2016). In the United States, EPA generic scenarios and emission scenarios are built into the ChemSTEER tool, with ExpoCast allowing exposure estimates to be made (US EPA 2016; US EPA 2018).

### Emission scenario tools available to assess exposure

Predicting emissions of chemicals from specific industrial processes, or from uses for the purpose of exposure assessment, can be uncertain. To help address this challenge, the OECD has developed Emission Scenario Documents (ESDs) that describe the sources, production processes, pathways and use patterns

**Box 2.3** **OECD Emission Scenario Documents (ESDs) (OECD 2018b)**

Emission Scenario Documents (ESDs) aim to quantify the emissions of a chemical into water, air, soil and/or solid waste. An ideal ESD should include the following stages:

1. production
2. formulation
3. industrial use
4. professional use
5. private and consumer use
6. service life of product/article
7. recovery
8. waste disposal (incineration, landfill)

of (groups of) chemicals (Box 2.3). ESDs also offer the possibility of obtaining well-supported estimates of exposure. These estimates can be used as default values in the assessment process unless more specific information on the use and release of a chemical becomes available (e.g. through industry data or as a result of further research). Wider use of the ESDs concept could be considered in the context of the sound management of chemicals and waste beyond 2020, as a potential tool to assist countries with limited resources to estimate exposure.

In the development of the ESDs, 54 use categories and 16 industrial processes have been applied. ESDs aim to quantify, for the specific steps in the life cycle, the emissions of a chemical into water, air, soil and/or solid waste based on available information or modelling results. They also cover the general mechanisms of diffuse emissions, the accumulation of long-life articles in society, and the relationship between the service life and the other stages in the life cycle chain (OECD 2008; OECD 2018b).

Guidance is available on the generic use of exposure scenarios to better quantify exposures (ECHA 2016). The main users of ESDs are expected to be those who need to estimate emissions of chemicals to the environment during production, use and disposal. This includes regulatory agencies, chemical producers assessing the potential impact of current and new products, and potential users of chemicals who are comparing alternatives. ESDs may also be used in developing estimates of releases for

© UNEP/Oli Brown, Ladies carrying loads near Makeni - Sierra Leone

PRTRs. ESDs and similar tools, including a number of generic scenarios developed by the US EPA (US EPA 2017e), have been widely used in national and regional contexts (ECHA 2016; ECHA 2018a).

### Computer modelling can help inform human and environmental exposure assessment

Insights into exposure levels can be obtained through the use of computer models. Modelling helps to improve the understanding of natural systems and how they react to changing conditions (e.g. exposure to hazardous substances, and the temporal and dose effects from the exposure) (US EPA 2017c). Models are used in risk assessment and risk management to describe the relationship between emissions and concentrations and to predict the outcome of management measures. An advantage of using models is that they allow the evaluation of results of many processes that occur simultaneously, which would otherwise be very difficult (van de Meent and de Bruijn 2007). Models may therefore be valuable for regulatory decision-making and the development of policies. Wider use of models to replace costly analytical monitoring programmes where appropriate – especially in countries with limited resources – could be promoted through training and broader capacity development support projects. There are also models for very specific purposes, such as estimating the overall persistence (Pov) and long-range transport potential of organic chemicals at a screening level (OECD 2018c).

Computer models are available for a number of parameters relevant to exposure assessment. Modelling categories include mass balance modelling; modelling that estimates concentrations and dispersion in environmental media; and multimedia modelling that provides information about the distribution and transport of released chemicals in environmental media. The OECD has made available an overview of 21 modelling categories, which include 56 specific models used in human and environmental exposure assessment (OECD 2012).

Many models are undergoing continuous improvement and refinement over time. The evolution of models covers, for example: different spatial and temporal scales; refined estimation of chemical properties and emission data; incorporation of additional environmental media and processes; and integration of sensitivity and uncertainty analysis in the simulations (Di Guardo *et al.* 2018; ECHA 2018b). For methodologically challenging substances, first generation models are now available to screen for exposure which take into account parameters that are relevant, notably, to nanomaterials (e.g. dissolution, agglomeration, transformation) (Meesters *et al*. 2014).

Such models enable the determination of ecosystem exposure and the prediction of environmental concentrations in freshwater, marine or terrestrial environments for ecological risk assessment. Wannaz *et al.* (2018) used a model predicting the differentiation in freshwater concentrations of a chemical (in this case triclosan [TCS], an antibacterial and antifungal agent used in consumer products) across an entire continent.

Several fate and exposure models allow the determination of human intake fractions via multiple exposure routes and pathways (e.g. inhalation, ingestion of drinking water, fish, meat, dairy products, above and below ground produce, dermal uptake). An example is USEtox, the consensus United Nations Environment Programme-Society of Environmental Toxicology and Chemistry (SETAC) toxicity model (Rosenbaum *et al.* 2008; Rosenbaum *et al*. 2011).

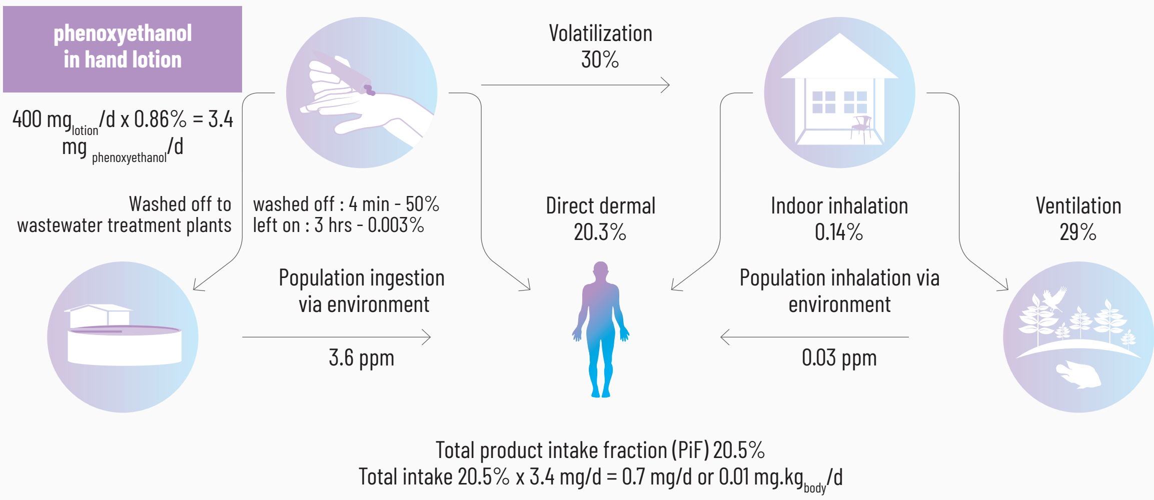
The combination of stochastic prediction of chemical content and product usage with exposure models makes it possible to compare model estimates of internal doses with the biomonitoring data that are becoming increasingly available at population level (Wambaugh *et al.* 2013; Csiszar *et al.* 2017). The external concentration or dose can then be compared with an external No Observed Adverse Effects Level (NOAEL) (see Part III, Chapter 4) or No Observed Adverse Effect Concentration (NOAEC) determined from animal studies.

### Estimating exposure from products is challenging because of data gaps

To quantify exposure to chemicals in products, the first step is to assess the chemical masses that enter the consumer near-field environment where products are located. Chemical composition and content have been relatively well-characterized for certain classes of products (e.g. for personal care and for cleaning). They are available in various databases (Goldsmith *et al.* 2014) or can be estimated based on chemical function (Isaacs *et al.* 2016). For other products such as articles or building materials, the composition is often unknown. Much wider disclosure of the chemical composition of products is needed in these cases, even though some databases that are based on product composition declarations exist. An example is the Pharos building materials database (Pharos 2018) (see Part I, Ch. 4 for other examples).

Chemical and product usage also depends on consumer behaviour. To characterize consumer behaviour, combined with the occurrence of chemicals in and releases from products, modelling of product and chemical usage is carried out at the population level. To cover these parameters, stochastic databases have been developed and applied that differentiate between average population and given population groups such as children or high-end users (Isaacs *et al.*

**Figure 2.2** **Transfer fractions to near-field and far-field compartments and the corresponding product intake fraction for phenoxyethanol used as a preservative at a concentration of 0.86 per cent in a hand lotion (based on from Fantke *et al.* 2016)**




Note: All percentages refer to the amount of phenoxyethanol applied.

The Figure indicates the different transfer fractions to near-field and far-field compartments and the corresponding product intake fraction for phenoxyethanol used as a preservative at a concentration of 0.86 per cent in a hand lotion. The 3.4 milligrams (mg) of phenoxyethanol applied on the hand is first transferred to an outer layer of the user's skin (epidermis) (20 per cent), to indoor air (30 per cent) and to the wastewater treatment plant (50 per cent if the lotion is washed off after four minutes, but only 0.03 per cent if is kept on for three hours). For this chemical the resulting total product intake fraction of 20.5 per cent takes place primarily via dermal uptake (20.3 per cent) through the outmost layer of the user's skin (the stratum corneum), with limited user inhalation of 0.14 per cent and negligible population ingestion and inhalation of less than 4 parts per million (ppm), resulting in an intake dose of 0.01 mg/kilogram body/day. Such high-throughput product intake fractions (PiFs) are available for more than 500 chemical ingredients in personal care products, with the PiFs varying from 0.001 per cent to 100 per cent depending on chemical properties (Csiszar *et al.* 2016), and for more than 8,000 chemical exposures in various products (Shin *et al.* 2015; Ring *et al.* 2018).

2014). Once the composition of products is better known, databases and high-throughput modelling tools are better suited to determine chemical releases from the product to the indoor environment. Based on this, it is possible to determine the product intake fraction (e.g. for personal care products, cleaning products, chemicals in articles and building materials, or food contact materials) (Isaacs *et al.* 2014; Fantke *et al.* 2016; Netherlands National Institute for Public Health and the Environment 2018). Chemicals released from products also undergo transport processes in the near-field before being transferred to the natural environment. It is therefore important to consistently combine near-field pathways (indoors and close-to-human environment) and far-field pathways (ambient air, soil, water environment). An example of the outcomes of a predicted intake fraction calculation is presented in Figure 2.2.

The life cycle of a given chemical or product may involve hundreds of different chemicals in its manufacturing. To address this complexity, the "environmental genome of industrial products" has been developed (Overcash 2016). This database for 1,600 industrial chemical products already contains manufacturing energy, process mass intensity, multimedia emissions, modular unit process flow diagrams, and by-products. This information makes it possible to assess and optimize the environmental performance of chemical manufacturing, while minimizing efforts to enter a new chemical due to its modular structure. Industry has also developed a programme which can be used on a voluntary basis by companies to carry out human and environmental risk assessments of ingredients in household cleaning products. In this programme exposure models are developed based on data and extrapolations which can provide useful information for this kind of assessments (Human and Environmental Risk Assessment n.d.).

## 2.3 Potential measures to further advance exposure assessment

Global action can be taken to promote wider awareness of available generic exposure assessment methods and models, so that all countries could use them to obtain insights into local human and environmental chemical exposure, keeping in mind that the conditions of use of chemicals differ between countries. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance exposure assessment:

- Compile exposure assessment methods in order to allow a better overview of existing tools.
- Scale up the estimation of chemical emissions and releases, as well as environmental and human (bio)monitoring programmes, to provide additional information for exposure assessments.
- Facilitate wider use of, and access to, generic exposure assessment methods and computer models, including through capacity development.
- Continue developing methods to determine releases from – and exposure to – chemicals in products.
- Continue developing methods to determine aggregate exposure across sources for the same chemical, and cumulative exposure across chemicals.
- Make additional efforts to increase transparency about the determination of parameters in chemical exposure models.

# 3/ Risk assessment: opportunities to improve and accelerate progress

## Chapter Highlights

New approaches to risk assessment take into account new hazard assessment and exposure assessment methods.

Regulatory frameworks are being strengthened in several countries to address emerging challenges in risk assessment, as well as to incorporate new data and approaches.

Large amounts of empirical data relevant for risk assessment have been generated and increasingly disseminated publicly.

A framework for assessing combined exposures to multiple chemicals is being further developed.

The use of screening-level, generic risk-based approaches and grouping of chemicals which are less complicated, and less resource intensive, is advancing.

Toolkits to assist in the risk assessment process have been developed for human health risks (WHO) and environmental risks (OECD).

Chemical risk assessments provide decision-makers with predictive analysis concerning the human and environmental health impacts of exposure to chemicals. Important building blocks for the risk assessment process were described in Part III, Ch. 1 (hazard assessment) and Ch. 2 (exposure assessment). This chapter features a broader discussion of risk assessment methods. Opportunities are identified for future work, based on lessons learned. Attention is also drawn to the wealth of relevant publications and services available from national governments and intergovernmental organizations.

## 3.1 The development of approaches to risk assessment is moving forward

### Different forms of risk assessment

Risk assessment can be undertaken from two different perspectives. A chemical-oriented, prospective risk assessment mainly aims to define conditions for the safe use of chemicals. An environmental media-oriented, retrospective risk assessment is intended either to assess the chemical load that is acceptable for a predefined compartment (e.g. a particular river or a human [sub] population). This approach also looks at whether – and to what extent – chemicals contribute to observed adverse human health or environmental impacts. In both cases risks to human health and the environment are considered. With respect to human health, assessments carried out by authorities often distinguish between risks to workers, consumers (from many different types of products) and the general population.

Risk assessments may take a number of different forms, depending on the particular risk management problem being addressed. Chiu (2017) identified the following levels of risk assessment, which have increasing levels of complexity:

- Screening and/or prioritization assessments identify potential areas for further consideration or analysis.
- Safety assessments determine whether existing or proposed exposure levels are "acceptable".
- Population-level assessments evaluate the impact of one or more risk management options on an overall population.

In conducting risk assessments, reliable data and proven methodologies are needed. Uncertainties may derive, for example, from lack of adequate data for dose/response calculations. They may also occur in extrapolating from animal test data to humans and across species, or in determining exposures across life cycles. Moreover, information relevant to assessing the special risks to vulnerable populations is often missing. These data gaps and uncertainties limit how the outcomes of risk assessments can be used in risk management.

### Strengthening regulatory frameworks to accelerate risk assessment

Criticism of chemical risk assessment approaches used in the past includes the fact that conducting them is resource-intensive, and that only a limited number of chemicals have been assessed for the risks they pose. Several major regulatory frameworks have therefore been adapted with the objective of facilitating the risk assessment of more chemicals within shorter periods of time. Adaptions also cover new areas such as the possible risks of nanomaterials (Laux *et al.* 2018). A specific framework for assessing manufactured nanomaterials has been put in place under REACH (Gottardo *et al.* 2017; EC 2018a), while the


© UN/Joydeep Mukherjee

US EPA is pursuing a comprehensive regulatory approach under TSCA to address nanoscale materials (US EPA 2017).

The amendment of TSCA by the Lautenberg Act of 2016 introduced a clear distinction between risk assessment and risk management (United States Congress 2016). It also mandated risk assessment for vulnerable populations and required that priority chemicals currently on the market (existing chemicals) be explicitly evaluated by the US EPA. For new chemicals, an affirmative safety finding by the EPA is required prior to market introduction. Current discussions revolve around implementation of the amended TSCA (American Chemistry Council 2018; Franklin 2018). In Canada a recent parliamentary review of the Canadian Environmental Protection Act of 1999 resulted in numerous recommendations related to risk assessment, including on vulnerable populations, endocrine-disrupting chemicals, cumulative risk assessment and priority-setting. These recommendations inform ongoing engagement with stakeholders to determine the future direction of chemicals management in Canada (Box 3.1).

In the EU, REACH has been subject to a recent major review. Although the review concluded, in principle, that REACH is fit for purpose, several shortcomings were identified and measures for improvement were suggested. The issues identified by the European Commission as most urgent were the non-compliance of many of the registration dossiers submitted by industry, and lack of updating of the data that form the basis for risk assessment. Further issues included the need to simplify the authorization process and to ensure a level playing field with non-EU companies (EC 2018b; EC 2018c).

### Improving empirical knowledge

Efforts have been undertaken to better organize and systematize empirical knowledge for chemical risk assessment, as well as to increase the availability of exposure, hazard and risk data to regulatory authorities, the public and other stakeholders. New Approach Methodologies

**Box 3.1** Canada's Chemicals Management Plan

The Canadian Chemicals Management Plan was launched in 2006 with the aim of reducing the risks posed by chemical substances to human health and the environment (Government of Canada 2016a). As of July 2018, over 80 per cent of the 4,300 substances identified in 2006 – during the categorization process – had been assessed. The remaining substances are expected to be addressed by 2021 (Government of Canada 2018a).

The Chemicals Management Plan Risk Assessment Toolbox offers a range of approaches to address the remaining substances (or groups) effectively by selecting an appropriate and fit-for-purpose approach in each case (Government of Canada 2016b). This ensures that efforts focus on the substances of highest concern and that stakeholders are engaged as efficiently as possible. Canada has also developed the Identification of Risk Assessment Priorities (IRAP) process, which seeks to integrate new information from a wider range of sources to track emerging issues and identify and prioritize substances that require further work (Government of Canada 2017a).

With the conclusion of the current Chemicals Management Plan nearing, Canada will be looking at new directions and objectives for chemicals management after 2020. It will also work on improving the Canadian Environmental Protection Act, 1999, which is the country's framework law on pollution prevention and toxic chemicals (Government of Canada 2018b).

are beginning to be applied in risk assessment, as illustrated by a number of case studies (Shah and Greene 2014; Karmaus *et al.* 2016; Pham *et al.* 2016). Important progress has been made in developing the concept of Adverse Outcome Pathways (AOPs) (Carusi *et al.* 2018) (see also Part III, Ch. 3) and in research on Aggregated Exposure Pathways (AEPs) (Teeguarden *et al.* 2016). Research is also advancing on the human exposome, a concept which includes examining the effects of exogenous chemicals and endogenous chemicals produced (or altered) in response to external stressors (Pleil 2015; Human Exposome Project 2019; EC 2015). Studies are exploring "if mechanistic understanding of the causal links between exposure and adverse effects on human health and the environment can be improved by integrating the exposome approach with the [AOP] concept" (Escher *et al.* 2017). For exposure-driven risk assessments of chemicals, however, more information on exposure patterns would be useful.

High-throughput screening generates hazard data relevant to risk assessments for thousands of chemicals. An example of work being carried out in this field is the US EPA's ToxCast programme, which includes publicly available high-throughput toxicity data on a large number of chemicals (US EPA 2018a). The further development and use of AOPs is important in understanding the mechanisms of toxicity for groups of chemicals. High-throughput screening is particularly useful in priority-setting. While these are all important steps with respect to limiting the use of test animals, in coming years much of the information needed to determine the (long-term) risk challenges of chemicals will still need to be derived through animal testing (ECHA 2017).

Ongoing activities result in large collections of empirical data, which are increasingly being made publicly available. Major data repositories that contain data on hazardous properties and classification, and inform risk assessment, include the US EPA's ChemView (US EPA 2018b), its CompTox Chemistry Dashboard (Williams *et al*. 2017; US EPA 2018c), REACH registration data at ECHA (ECHA n.d. a) and the OECD's eChemPortal (OECD n.d.). Data repositories on chemical occurrences and exposure are comparatively limited. Recent efforts include the IPCHEM portal of the European Commission (EC 2018d) and the NHANES human biomonitoring data from the National Health and Nutrition Examination Survey of the Centers for Disease Control and Prevention in the United States (US CDC 2018).

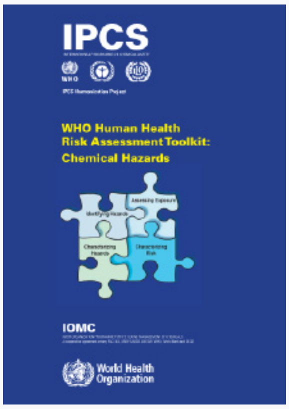
Over the last decade several large-scale programmes have been initiated in the United States and internationally to incorporate advances in molecular and cellular biology, -omics technologies, analytical methods, bioinformatics, and computational tools and methods in the field of toxicology. As noted in the report *Using 21st Century Science to Improve Risk-Related Evaluations* (United States National Academies of Sciences, Engineering and Medicine [US NASEM] 2017), "similar efforts are being pursued in the field of exposure science with the goals of: obtaining more accurate and complete exposure data on individuals and populations for thousands of chemicals over the lifespan; predicting exposures from use data and chemical-property information; and translating exposures between test systems and humans".

These efforts, separately and combined, help enlarge the knowledge base for risk assessment. However, they focus mainly on improving the empirical knowledge base for human health-oriented risk assessments. Improving the knowledge base for environmental risk assessments has received comparatively little attention – leading, for example, to a call to establish landscape-level monitoring of pesticide impacts (pesticidovigilance) (Milner and Boyd 2017). Moreover, such initiatives are currently mainly restricted to a small number of countries which already have significant experience in the field. Countries with limited resources for risk assessment often do not have widely available data repositories (Wang *et al.* 2015).

### International support to assist countries with risk assessments

A number of resources are available from international organizations to provide assistance with chemical risk assessments. The WHO, for example has developed a Human Health Risk

**Box 3.2** The WHO Human Health Risk Assessment Toolkit




The WHO Human Health Risk Assessment Toolkit (WHO 2010) (https://www.who.int/ipcs/methods/harmonization/areas/ra_toolkit/en/) provides users with guidance for identifying, acquiring and using the information needed to assess chemical hazards, exposures and the corresponding health risks in their given health risk assessment contexts at local and/or national levels. The Toolkit contains roadmaps for conducting a human health risk assessment; identifies information that must be gathered to complete an assessment; and lists electronic links to international resources where the user can obtain information and methods essential for conducting the human health risk assessment.

The Toolkit has been developed for public health and environmental professionals, regulators, industrial managers and other decision-makers who have at least some training in the principles of risk assessment, and who have a role in assessing and managing the human health risks of chemicals.

**Box 3.3** The OECD Environmental Risk Assessment Toolkit


The OECD's internet-based Environmental Risk Assessment Toolkit (OECD 2016) (http://www.oecd.org/env/ehs/risk-assessment/environmental-risk-assessment-toolkit.htm) provides access to practical tools for the environmental risk assessment of chemicals. It describes the general work flow of environmental risk assessment and provides examples of risk assessments. Links are provided to relevant tools developed by the OECD and its member countries that can be used in each step of the work flow.

Assessment Toolkit (WHO 2010) (Box 3.2). The OECD has developed an Environmental Risk Assessment Toolkit (OECD 2016) (Box 3.3).

## 3.2 Conceptual and methodological risk assessment solutions are emerging

### Weight of evidence and systematic review

In weight of evidence (WoE) evaluations a combination of information from several independent sources is used to provide sufficient evidence to meet an information requirement. The possibility to apply a weight of evidence evaluation, or a systematic review approach, in chemical risk assessment is included in a number of regulatory frameworks, including in the EU (Ågerstrand and Beronius 2016). The weight given to the available evidence depends on factors such as data quality, consistency of results, nature and severity of effects, and relevance of the information. Since WoE evaluations require the use of scientific judgement, it is essential to provide adequate and reliable documentation (ECHA n.d. b).

Canada applies WoE and precaution in risk assessment. Both WoE and precaution are influenced by uncertainty, so that all three concepts – weight of evidence, precaution and systematic review – should be considered together in decision-making. As noted by the Government of Canada (2017b), "a limited low quality data set will increase assessment uncertainty, reduce the strength and likely consistency of the WoE, thereby increasing the need to consider precaution. Conversely, a more robust data set will decrease uncertainty, resulting in the application of less precaution". A survey of frameworks for best practices in weight of evidence analyzes provides a review of 50 frameworks which have been used (Rhomberg *et al.* 2013).

Systematic review (SR) is a formal technique for reviewing existing evidence in order to answer a specific research question. It uses a predefined, multi-step process to identify, select, critically assess and synthesize evidence from scientific studies to reach a conclusion. It does not replace scientific judgement; rather, it uses a process to document the basis for scientific judgements, minimizing the risk of bias and error and maximizing transparency (Roth and Wilks 2014). A Navigation Guide for the Systematic Review Methodology was published in 2014 (Woodruff and Sutton 2014)

The SR method is described in detail in a handbook published by the United States National Toxicology Program (US NTP) (US NTP 2018a). The handbook will be updated as methodological practices are refined and evaluated and strategies are identified that improve the reliability, ease and efficiency of conducting systematic reviews A recently published US EPA document on the application of systematic review in TSCA evaluations provides an overview of the general principles used (US EPA 2018d). Both weight of evidence and systematic review are useful to inform the risk management decision-making process and make it more evidence-based.

### Defining better specific human and environmental protection goals

Protection goals in regulatory frameworks for chemical risk assessment and management are typically formulated in general terms. They demand, for example, avoidance of "harmful effects", "unreasonable risks" or "adverse impacts". However, hazard evaluations, exposure assessments and risk characterizations provide (often detailed) technical information that does not speak to broad protection goals. Therefore, it has been argued that specific protection goals should be better defined ("what to protect,

where and when") to improve, in particular, the environmental risk assessment of chemicals (Brown *et al.* 2017; Maltby *et al.* 2017). Further work on Adverse Outcome Pathways and integrated approaches to testing and assessment would help advance the linking of traditional toxicity endpoints (which are studied for hazard assessments) to impacts considered in regulatory decision-making in regard to risk levels. Currently, specific protection goals are mainly used in frameworks for retrospective, site-specific risk assessments, as these allow the definition and evaluation of "acceptable" versus "unacceptable" effects on species, populations and ecological communities.

To move prospective risk assessment methods forward and better define environmental protection goals, the use of the ecosystem services concept has been proposed by the European Food Safety Authority (EFSA) in the risk assessment of plant protection products and other chemical products (EFSA 2010; EFSA 2016). This entails systematic evaluation of impacts on potentially vulnerable key populations of organisms (the "ecosystem service providing units") and covers various dimensions. These may include biological entity, attribute, magnitude of effect, temporal and geographical scale of the effect, and the degree of certainty that a specified level of effect will not be exceeded. An ecosystem protection approach, if successfully implemented, provides a detailed map indicating conditions under which certain species groups might be at risk and what the overall impacts on biodiversity might be. It therefore allows the definition of appropriate risk management options. However, this approach is extremely data-demanding and might be best suited to chemicals (e.g. plant protection products) for which rich data sets are available.

### Improving risk assessment for chemical mixtures and cumulative exposures

Monitoring studies routinely show that humans, as well as organisms in the environment, are exposed to hundreds of individual chemicals from a variety of sources, resulting in cumulative exposures. Nevertheless, even modern regulatory frameworks mainly focus on the assessment of individual chemicals – disregarding the reality of cumulative exposures from different chemicals and products through different emission sources via a multitude of exposure pathways. Given that the risk of chemical mixtures in most cases exceeds the risks posed by individual chemicals, toxicological or ecotoxicological thresholds may not always be sufficiently protective (Kortenkamp, Backhaus and Faust 2009). There are GHS criteria for the classification of mixtures in which any impurities, additives or individual constituents of a substance which have been identified are considered if their properties exceed the cut-off value/concentration limit for a given hazard class (UN 2017).

The development and assessment of approaches and methods for mixture toxicity assessment have been subject to extensive reviews

**Box 3.4** **Assessing exposure to chemical mixtures: WHO and EFSA activities**

The WHO has been developing frameworks for human risk assessment of chemical mixtures (OECD 2011; Meek *et al*. 2011; WHO 2017a; US ATSDR 2018). The key purpose of this work is to provide an overview of available tools and practical recommendations to support the screening and prioritization of mixtures for the assessment and management of risks to human health associated with exposure to chemical mixtures from drinking water and its sources.

The European Food Safety Authority (EFSA) has also carried out a number of activities in this field related to pesticides and contaminants. As a first step prior to an assessment, the EFSA considers the problem formulation, defining the relevant exposure, hazard and population to be considered. The risk assessment itself is, in practice, conducted using a tiered approach for exposure assessment, hazard assessment and risk characterization. The tiers can range from tier 0 (a data-poor situation, default values) to 3 (full probabilistic models). Higher tiers require increasing knowledge about the group of chemicals under assessment (Meek *et al*. 2011; EFSA n.d.).

and guidance (OECD 2011; Meek *et al.* 2011; WHO 2017a; United States Agency for Toxic Substances and Disease Registry [US ATSDR] 2018). In the future new methods such as high-throughput screening could play an increasing role. In order for these methods to fulfil their promise, they should have relevance for whole animal models. Empirical knowledge of typical exposure patterns and the underlying drivers of mixture toxicity is still scarce and fragmented. They are the subject of ongoing research and evaluation. Given the complexity of assessing combined exposures temporally and spatially, the data demands compared with traditional risk assessments increase exponentially. Yet simple, robust and sufficiently protective rules of thumb are needed in order to allow at least semi-quantitative risk estimates to be conducted in support of regulatory action. The concept of an additional safety factor is currently being addressed, for example, by KEMI in Sweden and the National Institute for Public Health and the Environment in the Netherlands (Backhaus 2015; van Broekhuizen, Posthuma and Traas 2016). In the WHO and the EFSA work has been carried out to develop a framework for assessment of combined exposures to multiple chemicals (Box 3.4).

### Strengthening integrated risk assessments covering human health and the environment

Human well-being is closely related to ecosystem health and vice versa. It has become increasingly clear that media- or sector-specific efforts are insufficient to tackle broad-scale problems such as antimicrobial resistance development in the environment. The WHO One Health initiative has been developed to address aspects of this issue (Box 3.5). In the United States, the National Toxicology Program is engaged in the SEAZIT (Systematic Evaluation of the Application of Zebrafish in Toxicology) initiative (US NTP 2018b). Small aquarium fish species such as the zebrafish are used as model organisms to replicate human development, physiology and disease processes while avoiding the limitations of use of rodent-based models. Generating data on aquatic models could help evaluate biological processes related to both ecological receptors and humans. Fully incorporating these aquatic model organisms into modern toxicological investigations could also yield significant scientific and economic benefits (US NTP 2017).

### Better linking of risk assessment and risk management

The role of a risk assessor is to assess whether a risk of a certain chemical is "likely to arise". The role of a risk manager is to assess the "acceptability" of that given risk and, if needed, recommend risk management options to ensure an acceptable risk situation, taking into account trade-offs between risks and benefits of the use of the chemical concerned. In general, it would be useful for risk assessment to be better guided by risk management options and objectives. For example, risk assessors could be asked to provide certain levels of certainty or uncertainty in their assessment with respect to various risk management options, which would be particularly beneficial under multiple-risk conditions that require the evaluation of integrative response

**Box 3.5 The WHO One Health initiative**

The WHO One Health initiative is an approach to designing and implementing programmes, policies, legislation and research in which multiple sectors communicate and work together to achieve better public health outcomes (WHO 2018a; World Organization for Animal Health [OIE] 2018). The WHO works closely with the Food and Agriculture Organization of the United Nations (FAO) and the World Organization for Animal Health to promote multi-sectoral responses to food safety hazards, risks from zoonoses, and other public health threats at the human-animal-ecosystem interface, and to provide guidance on how to reduce these risks. While One Health currently targets a selected number of issues, mainly at the interface of veterinary and human medicine, its approach could be extended to the development of truly integrated chemical risk assessments, as envisaged by the WHO when this initiative began (FAO 2011; WHO 2017b; OIE 2018).

© Kekyalyaynen/Shutterstock, water recycling on sewage treatment station

options. This could be relevant, for example, when assessing the consequences of exposures to complex chemical mixtures or evaluating chemical alternatives. Detrimental risk-risk trade-offs, which might occur as a result of different amounts of hazard and exposure information being available for different chemicals, could be reduced (Sahlin and Rundlöf 2016). Already in 2009, the National Research Council in the United States published a report which recommended that risk assessments be more closely linked to problem formulation and problem solving, and that the level of detail in a risk assessment match the question that needed to be addressed (United States National Research Council [US NRC] 2009).

The WHO *Guidance Document on Evaluating and Expressing Uncertainty in Hazard Characterization* (2017c) finds that "the process of evaluating human health effects as a function of (potential) exposure [...] necessarily involves uncertainties" associated with extrapolating results from hazard assessment. "Ignoring these uncertainties may lead to incomplete risk assessments as well as suboptimal decision-making and risk communication." Risk assessors therefore have to take uncertainty explicitly into account. "Effective risk assessment and subsequent risk management does not require the elimination of uncertainty; rather, it requires that any such uncertainty is made visible and has been taken into consideration."

### Solution-oriented approaches in environmental risk assessment

Demand for solution-oriented approaches is increasing not only in the context of chemical risk assessment, but also in that of global environmental assessments generally (Jabbour and Flachsland 2017). To foster tighter coupling of chemical risk management with risk assessment in identifying appropriate action, the concept of solution-focused risk assessment has been proposed (Finkel 2011) (Box 3.6). van Wezel *et al.* (2017) used a solution-focused perspective for chemicals in European water bodies. Instead of another database on toxic effects and chemical exposures, they developed one that provides mitigation options for improving water quality. A solution-focused and systems-oriented approach, combined with such a mitigation database, offers a common, action-oriented perspective among stakeholders on the effects on water quality of possible mitigation options throughout a

**Box 3.6** Solution-focused risk assessment (Finkel 2011)

Instead of beginning by asking “How bad is the problem?”, solution-focused risk assessment asks “How good are the solutions that could be applied to the problem?” Rethinking risk assessment this way could provide three types of benefits:

- It could help to interrupt an endless cycle of analysis (sometimes referred to as “paralysis by analysis”). When the goal is to know enough to decide, rather than to “know everything”, natural stopping points may emerge.
- It could lead sooner to decisions that succeed in reducing risk, rather than assessments of how much risk reduction would be optimal.
- It could highlight ways to resolve multiple risks and, simultaneously, avoid unnecessary and poorly thought out risk-risk trade-offs.
- Affected stakeholders might then be more easily involved in discussing what should be done to address the problem.

chemical’s life cycle in various sectors and at various locations in the water system.

Risk assessment, in its role of defining an “acceptable operating space” for industry and consumers (as a proactive tool to help avoid harm in the first place), might not be easily amenable to this approach, which seems best suited to media- and site-specific assessments in order to provide options for taking action as early as possible. When it has been demonstrated that a river is polluted by untreated effluents, or that decreasing fertility in a community is due to endocrine-disrupting chemicals, the application of this approach might be most useful, depending on national practices.

### Risk communication

Communicating risk information is a challenge within countries and internationally. In order to be effective, risk communication needs to address psycho-social aspects of chemical risk perception and management. Since it is characterized by uncertainty, rapid changes and developments, risk communication requires flexible communication tools and channels. It should therefore, as appropriate, exploit new technology including social media. Two-way communication via interactive media also allows feedback that can help improve future risk communication policies and practices. Groups with whom effective risk communication is essential include workers, public authorities, health care providers and the media; the steps to be taken before an accident occurs include providing information to the public about relevant chemical products (emphasizing the difference between hazard and risk) (OECD 2002).

In recent years technological advances have improved many types of scientific risk information dramatically. However, valuable information can easily go to waste if not effectively communicated to the people who need it so they can make decisions. Effective communication helps technical experts to develop and share data. It also enables professional users to understand the data, while it influences how many ordinary people take actions to reduce risk. Because communication is a process, it should be considered throughout every stage of risk assessment (United Nations Office for Disaster Risk Reduction [UNISDR] 2017). (See also Part III, Ch. 4 and, in relation to chemical accidents, Part III, Ch. 6)

## 3.3 How can risk assessment evolve?

### Grouping of chemicals

Currently, chemicals are most often assessed compound by compound. Risk assessments that evaluate whole chemical groups could substantially reduce the burden on the regulatory system and increase efficiencies in public and environmental health protection. Group risk assessments are currently limited to complex chemical mixtures such as petroleum products. The OECD has developed guidance for the grouping of chemicals and read-across approaches (OECD 2014; OECD 2018). Although grouping is limited at this time to the hazard assessment of data-poor chemicals, it might be a starting point for the development of similar approaches for risk assessments. Canada has already used grouping strategies to assess nine key groupings of substances under the Chemicals Management Plan (Government of Canada 2016b). The European Commission and the ECHA are also looking at possibilities for the increased use of grouping of chemicals to speed up the identification and management of those of concern (KEMI 2018; ECHA n.d. c).

Research suggests the promise of the grouping methodology. The results of a recent study show that a combination of bioactivity and chemical descriptors can accurately predict a range of target organ toxicity outcomes in repeat-dose studies. Further experimental and methodological improvements may further increase predictivity (Liu *et al*. 2017). Another recent publication concludes that an *in silico* tool which can predict toxicity values with uncertainty of an order of magnitude or less can be used in combination with exposure assessment to assess risks of environmental chemicals quickly and quantitatively when traditional toxicity data or human health assessments are unavailable. This tool could fill a critical gap in the risk assessment and management of data-poor chemicals (Wignall *et al.* 2018).

One proposed generic risk-based approach is the concept of Threshold of Toxicological Concern (TTC). TTC assumes that an exposure below a certain threshold concentration (which is specific for a defined group of chemicals) is without adverse toxicological consequences (EFSA 2012). It has been used to define such exposure concentrations for the members of a given chemical class. This approach could also be particularly useful in deciding which chemicals should not be given high priority for further work. Full risk assessments would then only be required if the exposure level exceeded the TTC. An advantage is that applying the TTC would not require substance by substance hazard data. However, its validity hinges on a valid chemical grouping, sound estimation of the TTC for each chemical group, and reliable exposure assessment. Canada has experience with using a TTC-based approach in a regulatory setting (Environment and Climate Change Canada 2016; Environment and Climate Change Canada and Health Canada 2017)

### Better integration and harmonization

Chemical risk assessment is largely anchored in a national (regulatory) context, rather than being organized at the international level under an overarching framework as is the case with, for example, efforts to combat global climate change and protect the ozone layer. Efforts to address certain priority hazardous chemicals are implemented in a complex set of intertwined, legally independent treaties and programmes that address a small number of chemicals (Selin 2013). The lack of a holistic global strategy for chemical hazard and risk assessment and management also hampers knowledge transfer and transparency. Ways to fill this gap could be explored in the context of the sound management of chemicals and waste beyond 2020 (Backhaus, Scheringer and Wang 2018).

Improved integration and harmonization may also be valuable at the technical level (Wilks *et al.* 2015). Human health-oriented and environmental risk assessments use similar techniques, sometimes even employing identical (eco)toxicological test systems, chemical monitoring strategies and data integration/evaluation approaches. Better connecting human health and environmental perspectives in an integrated assessment by generating empirical data and models that consider both human health and environmental protection would vastly improve the efficacy of the risk assessment process.

The report *Using 21st Century Science to Improve Risk-Related Evaluations* (US NASEM 2017) makes recommendations for integrating new scientific approaches into risk-based evaluations. It proposes how best to integrate and use the emerging results in evaluating chemical risk and considers whether a new paradigm is needed for data validation; how to integrate the divergent data streams; how uncertainty might need to be characterized; and how best to communicate new approaches so that they are understandable to various stakeholders.

### Generic risk-based approaches

Conducting an in-depth chemical risk assessment can be resource-intensive. In certain cases, however, a generic and science-based, risk-based approach – which is less costly, but fit for purpose – can be used (Hansen 2017). For example, this approach could be used to identify:

- chemicals with low exposure that are unlikely to present unreasonable risks;
- low-hazard chemicals (e.g. chemicals that do not need to be classified according to the GHS criteria and therefore are unlikely to present unreasonable risks); and
- combinations of hazards, uses and exposures that are likely to present risks.

Several strategies have been developed so that regulatory decisions can be taken (if circumstances permit) without requiring the full suite of hazard and exposure assessments. These approaches do not directly replace full risk assessments; however, they provide decision-making criteria for determining whether there is a case to answer and/or they often guide prioritization efforts. Canada, for example, has developed the Chemicals Management Plan Risk Assessment Toolbox, which offers a range of approaches to address substances (or groups) effectively by selecting an appropriate and fit-for-purpose approach. Such examples include the Rapid Screening Approach that may use either qualitative or quantitative data for assessments and are typically applied to substances that have lower potential for exposure and risk; or the adoption of existing hazard characterizations from international organizations (Government of Canada 2016b). A generic risk-based approach could also be to consider that there are combinations of hazards and uses for which risk is inevitable because exposure cannot be controlled, such as in the case of carcinogenic, mutagenic and reprotoxic (CMR) chemicals in consumer products and preparations.

Methods which are only hazard-based are sometimes used in voluntary approaches, particularly when possibilities to substitute hazardous chemicals with less problematic alternatives are being explored. An example is use of the SIN (Substitute It Now!) List approach (International Chemical Secretariat n.d.). To a certain extent, eco-labelling is also based on the consideration of hazards. High-throughput screening for hazards, accompanied by read-across methods, can help to facilitate the prioritization of chemicals for a full traditional risk assessment.

### Chemical assessment in countries with limited resources

In countries with limited resources, a number of economic, technical and administrative obstacles may impede the adaptation of elaborate risk assessment frameworks developed in countries with greater resources. The lack of an applicable, overarching international framework, and prevailing difficulties in the implementation of already existing instruments, pose additional problems. As it might not always be possible to make a full risk assessment, management on the basis of hazard is practised by some countries and is considered a legitimate approach to sound chemicals management in specific cases – including, for example, chemicals that are highly hazardous, that do not have thresholds, that are persistent or bioaccumulative, or that have non-monotonic dose responses, or where conditions of use are such that generic exposure assessments are not valid.

### Towards enhanced knowledge-sharing

In the beyond 2020 chemicals and waste strategy, consideration could be given to how best to promote the best global use of the rapidly increasing volume of publicly available hazard and risk information. This could be achieved, for example, through continued technical harmonization of the scientific methods used in the generation and assessment of the necessary data, including harmonization of data

formats. The WHO Chemical Risk Assessment Network supports global efforts to assess and manage the risks associated with exposures to hazardous chemicals. Established in 2013, it involves institutions with chemical risk assessment activities (WHO 2018b). The use of existing OECD products in this respect could be considered. Countries with limited resources would then be better placed to benefit from the results, including priority-setting and in-depth assessments (generated and made publicly available through national and regional programmes), and to apply them in their national contexts.

## 3.4 Potential measures to further advance risk assessment

Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance risk assessment:

- Facilitate global use of the increasing volume of publicly available risk-related information, particularly by countries with limited resources.
- Develop and adapt chemical risk assessment methods in order to facilitate their use in countries with limited risk assessment capacity.
- Improve the knowledge base for environmental risk assessment (e.g. through chemicals release data).
- Further develop risk assessment methods for chemical mixtures and chemicals in products, as well as integrated risk assessment approaches covering human health and the environment.
- Explore further how screening-level, generic risk-based approaches can be used, where these approaches are fit for purpose.
- Take steps to facilitate, where appropriate, the use of risk assessment methods in developing countries, in order to further develop and harmonize methods for the risk assessment of chemical mixtures and chemicals in products, and consider developing more specific protection goals for use in risk assessment.

# 4/ Risk management decision-making: making it work in all countries

## Chapter Highlights

Safety data sheets and labelling, based on the GHS, provide the foundation for risk management. However, globally there are important implementation and knowledge gaps.

Regulatory decision-making can stimulate frontrunner companies to undertake sustainable innovations.

Government regulatory actions, non-regulatory strategies and voluntary initiatives may be mutually supportive when used in a concerted way.

Socio-economic analysis that addresses the costs and benefits of action and non-action is useful to inform decision-making. Nevertheless, caution in the interpretation of results is required.

The IOMC Toolbox for Decision-Making in Chemicals Management can assist countries in identifying the most appropriate risk management instruments and approaches.

Risk assessment is a scientific approach which provides decision-makers with robust assessments of the actual or potential impacts of exposure. It is an approach that takes socio-economic considerations into account. This chapter addresses important aspects of the chemical risk management decision-making process: information needs; the available support tools; how regulatory and voluntary actions can be complementary; and how countries with limited resources can engage in risk management (e.g. on the basis of the GHS).

## 4.1 From chemical risk assessment to risk management

Risk management decision-making is a process whereby risk managers, policymakers and scientists work together closely to find innovative ways to select the best option(s) for a course of action to ensure that human health and the environment are protected. In most cases a chemical risk assessment is a solid basis for chemical risk management. The interface of the risk assessment and the risk management process is referred to as "risk characterization". In risk characterization, exposure and hazard are compared in order to determine a No Observed Adverse Effect Level (NOAEL) – that is, the greatest concentration or amount of a substance found in a test to cause no adverse reactions by the target organism for a specific endpoint (further described in Duffus, Nordberg and Templeton 2007). Since the NOAEL is usually determined through animal testing, assessment factors are used to convert NOAELs to a reference dose that may be applied in human risk assessment and risk management.

The outcome of risk characterization is often presented in the form of a risk quotient that compares the (expected) concentration of a chemical in the medium of interest (e.g. the human body, ambient air, an aquatic ecosystem) with the maximum concentration deemed safe under normal circumstances. Certain population groups are more vulnerable to exposure to chemicals due to biological, social, economic or other factors. These groups include, among others, the elderly, children, pregnant women and the poor. The possible risks for these vulnerable groups require special consideration in risk management decision-making, especially during the risk characterization process.

### How much information is needed for risk management decision-making?

Risk assessment and risk management processes that aim at preventing harm to human health and the environment require a significant amount of scientific information. This information is, at times, characterized by uncertainty. In decision-making to protect human health and the environment, where there is incomplete knowledge or lack of scientific certainty, precautionary actions are often considered, in accordance with Principle 15 of the Rio Declaration on Environment and Development

Principe 15 states that "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (UN 1992). A logical framework for using the precautionary principle in chemicals regulation has been developed to help regulators in the EU work through the process of considering whether a combination of concerns and uncertainties justifies taking precautionary measures of control (Milieu, T.M.C. Asser Institute and PACE 2011). This framework underlines the importance of documenting the evidence of concerns and uncertainties, so that the decision-maker can be confident that applying the precautionary principle is appropriate.

Addressing data uncertainties concerning the exact magnitude of the risk, as well as carefully considering options for the implementation of risk management, can at times make the risk management process complex. While chemicals' hazards cannot be changed, exposures can be controlled to eliminate or minimize harm to human health and the environment, a hierarchy can be used in applying controls. In the field of occupational health, for example, elimination/substitution of the hazard is a preferred approach and is at the top of the hierarchy. This is followed by subsequent steps, among which are engineering controls, administrative controls (including changes in work practices) and, finally, use of personal protective equipment (PPE) (US CDC 2015).

In controlling exposure, a number of information uncertainties also exist and must be taken into account. Reliable measurements of exposure are often scarce and limited to the workplace. While monitoring data could be used in exposure assessment, they are available for only 1 to 2 per cent of the chemicals on which there are some toxicity data (Egeghy *et al.* 2012). A further challenge in determining the risk of chemical exposure to human health or the environment is that information describing how chemicals are used does not always cover the whole life cycle. Fortunately, even when uncertainties exist and not all the desired information is available, the use of Emission Scenario Documents (ESDs) and models can in most cases help to provide the necessary insights (OECD 2018a; ECHA n.d. a). In the case of pesticides, surveillance programmes are also an important basis for risk management. Activities in these programmes include the investigation and evaluation of adverse health effects related to acute pesticide exposure and the analysis of pesticide exposure data.

## 4.2 Safety data sheets and labelling: implementation and gaps

### Safety data sheets and labels: important tools for risk management

An important first step in risk management is to ensure good access by workers and consumers to chemical hazard and risk information. Such information is often made available in the form of product labels, pictograms and safety data sheets (SDS) (Ta *et al.* 2010; Sathar, Dalvie and Rother 2016; ECHA n.d. b). SDS and labels are the basic hazard communication tools for hazardous chemicals as regards their manufacture, storage, transport and other handling interactions (Lee *et al*. 2012; Dalvie, Rother and London 2014). International Chemical Safety Cards (ICSC) are information tools prepared through a peer-reviewed process in order to provide safety and health information on chemicals in a clear and concise way (ILO 2018; WHO 2018a). By promoting safe use of chemicals in the workplace, these cards also support implementation of the ILO Chemicals Convention (ILO 2017).


© UNITAR/Andrea Cararo, Labelling of containers in a leather chromium tanning factory

Hazard and safety communication elements such as pictograms, hazard statements, precautionary statements and guidance, and a harmonized format for the preparation of SDS are the key constituents of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) described in Part II, Ch. 2.4 (UNECE 2017; UNECE n.d. a; UNECE n.d. b). The GHS is a common starting point that can help risk managers ensure the appropriate handling and safe use of chemicals (Dalvie, Rother and London 2014). Effective implementation of classification and labelling is an initial risk management measure that can, in principle, be implemented consistently in all countries even when limited resources are available. National or regional legislation on classification and labelling, based on the GHS, is necessary to ensure solid implementation and enforcement.

The GHS is (partly) in force in 72 countries. In some countries a transitional period is in effect before the GHS becomes mandatory. In other countries it has not yet been implemented (UNECE n.d. a) (see Part II, Ch. 3). Obstacles to fully harmonized implementation of the GHS include discrepancies in the classification process, and in the different information sources across countries and regions, mainly due to varying selections made from hazard testing and estimation results (Morita and Morikawa 2011) and legal implementation gaps (Persson *et al.* 2017). Continuous training on classification and awareness-raising in a global or regional setting would help governments to build expertise on the implications of GHS, and to ensure that its provisions are reflected in legal instruments (Dalvie, Rother and London 2014).

While labels provide important first information to anyone who handles, uses, stores and/or transports hazardous chemicals, SDS provide more comprehensive information. They are product-related and enable the employer to develop and implement worker protection measures specific to the workplace (United States Occupational Safety and Health Administration [US OSHA] 2012; US OSHA 2013; UNECE 2017). There are, however, several gaps in the way SDS are prepared and applied in the workplace, meaning that workers may not be correctly informed and may be at risk. For example, studies show that many products contain chemicals that are not declared on the SDS, or that chemicals may be found at higher concentrations than indicated on the SDS (Nicol *et al.* 2008).

Where there is a mixture of chemicals, most SDS combine the hazards from all the components of the mixture, which may result in understating the actual risk in the event that synergistic effects result from the interaction between the components (ChemSafetyPro 2018; ECHA n.d. c). Similarly, an SDS may not address possible synergistic effects with other chemicals to which workers may be exposed. Since chemical suppliers could be unaware of all possible applications of their chemical(s), precautions for use cited in the SDS may not be appropriate for all situations. It should also be noted that while SDS often reach the first producer of an article, in most cases they do not reach the next levels in the supply chain and are normally not provided to retailers and consumers, who will therefore be unaware of the information in the SDS (Massey 2008). A study by Safe Work Australia found that for nanomaterials only 18 per cent of SDS contained reliable information to appropriately inform an occupational risk assessment (Frangos *et al.* 2010).

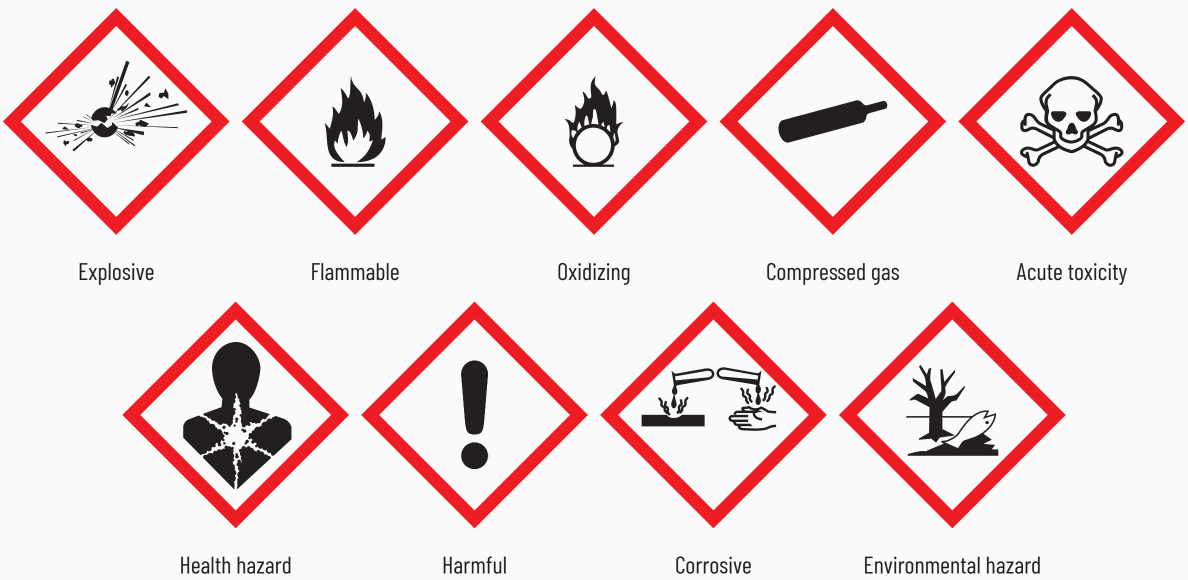
### Are hazard and risk communication tools well-understood?

Chemical risk communication is of vital importance to make sure workers and the general population are well-informed and take protective measures in the use and handling of chemicals. In developing and evaluating the effectiveness of chemical risk communication tools, multidisciplinary expertise is required to ensure comprehensibility of chemical hazard information. Effective risk communication needs to take into account a range of aspects, including information sources, delivery channels, training methods and the target audience. Figure 4.1 shows some frequently used pictograms.

Several studies have investigated the level of comprehensiveness of information on chemical hazards among workers and consumers. They have identified demographic characteristics, gender, level of education and cultural differences as some of the key factors that influence understanding of information on a label or an SDS (Sathar, Dalvie and Rother 2016) (see also Part III, Ch. 6). A study carried out in South Africa concerning the comprehensibility of chemical hazard communication elements revealed that understanding of hazard communication labels and safety data sheets was generally low. Symbols such as the skull and crossbones (98 per cent) and flames (93 per cent) were relatively well-understood (either correct or partly correct responses), but the majority of hazard symbols were of moderate to poor comprehensibility. There were significant levels of critical confusion (5 per cent or above) in the case of symbols for corrosive and compressed gases (Dalvie, Rother and London 2014).

Rother (2018) has identified a range of factors to ensure that information on pesticides' hazard and risk, as well as related safety measures, are effective, particularly in low- and middle-income

**Figure 4.1** Hazard pictograms according to the GHS (UNECE n.d. b.)



countries. These factors include: a correct label must be on the pesticide container or packet; the label must be in the language of the end user; the end user must be literate and able to read the label language; the end user must be able to understand the content of the label (e.g. symptoms of poisoning); and the end user must have the means to implement the instructions (e.g. correct measuring and mixing instruments) as well as to apply safety precautions. Safety precautions include the use of correct PPE for the acute and chronic toxicity levels of the product, according to the relevant WHO and GHS hazard classification system (Rother 2014; Rother 2018). Consumers often assume that products with an eco-label or without hazard pictograms do not contain harmful substances (Hartmann and Klaschka 2017). These outcomes point to the need for well-considered information strategies to communicate chemical risks in consumer products.

## Safety data sheets for nanomaterials remain a challenge

Engineered nanomaterials are a growing class of materials being manufactured and introduced into multiple business sectors (Eastlake *et al.* 2012). An evaluation of 97 nanomaterial-related SDS, according to the criteria set by the GHS, found that most of these SDS did not include sufficient information on the safety of nanomaterials such as their toxicity and physicochemical properties (Lee *et al.* 2012). It was concluded that this lack of information in the nanomaterial SDS could mainly be attributed to lack of toxicity and physicochemical property information on nanomaterials; unawareness of the effectiveness of conventional exposure controls, such as local exhaust ventilation and encapsulation or PPE, in protecting against nanomaterial exposure; lack of information on emergency and firefighting measures; and lack of knowledge on how existing

regulations apply to nanomaterials (Eastlake *et al.* 2012; Lee *et al.* 2012).

Guidelines published by the WHO offer several recommendations for protecting workers from the potential risks of manufactured nanomaterials (MNMs). The guidelines address assessment of MNM health hazards and exposure, controls, health surveillance, and training of workers. One of the 11 recommendations is to assign hazard classes to MNMs on safety data sheets according to the GHS (WHO 2017).

## 4.3 Government action and proactive voluntary industry initiatives can complement each other

### Government action and regulatory substitution goals can encourage voluntary initiatives

Governments are responsible, in the first place, for promulgating regulatory measures. They can also play an important role in fostering voluntary action in industry, for example by developing or promoting codes of practice, environmental quality objectives or guidelines, environmental release guidelines, or environmental performance agreements. The Canadian Chemicals Management Plan, for example, includes provisions for encouraging such non-regulatory initiatives (Government of Canada 2012).

Substitution goals set by public authorities can be a driver through facilitating voluntary frontrunner action. In Europe, the listing of substances of very high concern (SVHC) and the Candidate List for inclusion of substances for authorization under Annex XIV of REACH convey the intention of the regulator to take risk management action (ECHA 2011). In anticipation of such action, Hoffman-La Roche, for example, implemented a detailed global substitution action programme, which not only incorporates the necessary elements to comply with REACH in advance of regulatory timelines, but also uses business considerations and innovation practices to evaluate and test alternatives (Buxton 2016).

The OECD has developed a table of regulations and restrictions which includes substances/chemicals that are legally or voluntarily restricted or recommended for restriction by a number of stakeholders due to their hazards, or have been examined by jurisdictions based on potential concerns of a similar nature (OECD n.d.). It includes 55 lists of "chemicals of interest" from 12 categories of national or international legislation and programmes. These lists of substances/chemicals can be of general interest for voluntary substitution activities.

### Advancing voluntary action beyond compliance can be an advantage

A growing number of industry-based voluntary initiatives that are led by individual enterprises or industry associations support, and in some cases go beyond, regulatory measures. These initiatives are based on, among others, the idea that voluntary action may in some cases be more flexible and cost-effective than regulations. Factors driving voluntary action of companies may include, for example: appealing to consumers who demand "green" products; pre-empting government regulations; seeking regulatory relief from regulatory action; or gaining a competitive advantage (Videras and Alberini 2007). Similarly, the importance of building confidence and trust in society and obtaining a "social licence to operate" encourages companies to take voluntary action and behave in a legitimate, transparent, accountable and socially acceptable way to lower risk for business (World Business Council for Sustainable Development [WBCSD] 2015).

Frontrunner companies can be found among the chemical industry, downstream sectors and retailers. Leading companies in the chemical industry, in downstream industries and in retail sectors have recognized the benefits and have initiated voluntary action, often ahead of potential regulatory action. These frontrunner companies can be considered as key drivers accelerating a transition to greener and sustainable chemicals alternatives in their sectors, at the same time addressing improvements in economic performance as well as the ecological footprint and potential health impacts of their products and production.

In the chemical industry a number of companies (e.g. BASF) have introduced portfolio sustainability assessments so as to act in a timely manner and make necessary changes prior to possible regulatory changes or new mandatory environmental or health requirements, in order to proactively steer their overall product portfolios towards improved sustainability outcomes (Consultancy.uk 2017). An example of proactive action in a downstream sector, the electronics industry, is the commitment by Apple to phase out brominated flame retardants and polyvinyl chloride in all its products, while other electronics companies have made partial progress by eliminating those substances in selected devices (Cook and Jardim 2017). S.C. Johnson, a formulator of chemical-intensive products widely used in households, launched a successful chemical classification process to rate raw materials based on their impact on human health and the environment (further explained in Part IV, Ch. 7).

In the retail sector major companies see "the value of getting ahead of the curve on enacting rules ahead of governments" and have therefore made significant progress in adopting safer chemicals policies. These policies drive reductions and substitutions of toxic chemicals in products and represent a commitment to publicly disclose all product ingredients in order to respect consumers' right-to-know (GreenBiz 2018). Large retailers like Walmart in the United States, for example, stopped selling flooring products containing phthalates ahead of any future regulatory restrictions on these chemicals (Franklin 2015; Franklin 2016). Similarly, in Europe concerns about consumer safety and possible regulatory action triggered action by Coop Denmark to proactively replace certain fluorinated chemicals in food packaging products with a sustainable alternative (Green Science Policy Institute 2013). Many more examples of such actions have been described (Geiser 2015) (see also Part III, Ch. 4).

### Ensuring the effectiveness of voluntary action

While voluntary initiatives can be useful, it is critical for governments to monitor the effectiveness of these initiatives, especially if they precede intended regulatory action. A certification and/or accreditation mechanism can help verify voluntary standards. Similarly, in certain cases conformity assessment of products by a public or private auditor could provide a check on the implementation of voluntary initiatives (Henson and Humphrey 2009). Depending on the outcomes of such monitoring, governments may need to reserve the position that regulatory follow-up can be put in place when envisaged policy objectives are not met or not met fast enough.

### Responsible procurement as a vehicle for risk management and creation of markets for safer chemicals

It is well-recognized that responsible procurement and supply chain management (further discussed in Part IV) provide opportunities for public (and private) organizations to support practices that are likely to improve health and labour conditions, for example in those developing countries where production and processing often take place (Boström *et al.* 2011). An analysis of a global transition towards public spending on goods and services which maximizes environmental and social benefits indicates that commitment to implementation has increased (UNEP 2013). It describes the widespread use and recognition of public procurement as a key element driving innovation and sustainable development in all policy arenas. Similarly, demand for safer chemicals offers opportunities for private organizations to shift the marketplace towards more sustainable products and services.

A review based on case studies from several organizations, and their approaches to identifying and purchasing safer alternatives, describes the benefits and lessons learned from their sustainable purchasing programmes (Perlmutter 2015a). The Danish supermarket chain Coop, for example, works with suppliers to eliminate endocrine-disrupting chemicals and other chemicals of concern in products sold in its stores; Kaiser Permanente, active in the health care sector in the United States, has developed a chemical score card and works with suppliers to eliminate or reduce the purchase of products that expose its workers and patients to toxic chemicals (Perlmutter 2015b). Organizations that offer products with safer chemistries need to know about potentially harmful substances in the intermediate products they purchase, and therefore have to engage on safety aspects with their suppliers and strengthen supply chain management in this respect. Eco-labelling can play an important role in this context, including by helping customers from both the public and private sector identify greener and more sustainable products, as further explored in Part IV, Ch. 7.

## 4.4 The potential of private standard-setting in international chemicals and waste management

### International private standards and harmonization initiatives

The increasing complexity of global supply chains, and addressing risks across the supply chain, create challenges for traditional regulatory approaches and international policymaking. In a number of international policy arenas private sector standards have emerged as a complement, and a response to, deadlocks in global public action (Humphrey 2017). Prominent examples

**Table 4.1** Forms of standards (adapted from Henson and Humphrey 2009) complemented with international examples relevant to chemicals and waste management

| | Public | Private |
|---|---|---|
| **Mandatory** | Regulations<br><br>Annexes A and B of the Stockholm Convention on Persistent Organic Pollutants (POPs)<br><br>OECD Council Decision on Mutual Acceptance of Data (MAD) | Legally (or policy) mandated private standards<br><br>International standards for flammable low global warming potential (GWP) refrigerants recognized by Parties to the Montreal Protocol |
| **Voluntary** | Public voluntary standards<br><br>Globally Harmonized System for the Classification and Labelling of Chemicals (GHS)<br><br>Codex Alimentarius Commission | Private voluntary standards<br><br>Responsible Care®<br><br>Manufacturing Restricted Substance List (MRSL) of the Zero Discharge of Hazardous Chemicals (ZDHC) Programme |

include the Forest Stewardship Council, the Marine Stewardship Council (Humphrey 2017), and private governance in international forest regulations (Bernstein and Cashore 2007).

Public and private standards can operate and interact in different ways. Four forms of public and private standards can be identified, as shown in Table 4.1 (Henson and Humphrey 2009). While public standards are developed though a formalized process, and adopted by public bodies, private standards can be more broadly conceived as "written documents adopted by a non-governmental entity which lays down rules, guidelines and/or characteristics, for common or repeated use, for products or related processes and production methods, including transport" (Scott *et al.* 2017).

### Private standard-setting relevant to chemicals and waste management

Several types of private standards can be distinguished: individual company standards, collective national standards, and collective international standards (Henson and Humphrey 2009). Concerning international private standards, a number of initiatives in recent years have sought to advance harmonization for specific aspects of the sound management chemicals and waste that are not addressed through treaty law or international (public) bodies. Initiatives are driven by the chemical industry or specific downstream industry sectors, or include initiatives cutting across industry sectors. They have been advanced through a range of fora, raising the question of how linkages with relevant private standing-setting may be established under a future approach on chemicals and waste management beyond 2020.

An example of private governance and standard-setting in the chemical industry dating back to 1985 (and currently covering 68 countries) is Responsible Care®, which is supported by the International Council of Chemical Associations (ICCA) (ICCA 2015). Responsible Care® is a voluntary commitment by the global chemical industry to drive continuous improvement and achieve excellence in environmental, health and safety and security performance. In 1995 the chemical distribution industry officially joined the programme (International Chemical Trade Association n.d.). The Responsible Care Charter has been signed by CEOs representing more than 96 per cent of the world's largest companies. In the United States, a Responsible Care® Management System has been established that includes independent third-party certification and transparent reporting and performance metrics (ICCA 2015). This approach has the potential to serve as the benchmark for monitoring and assessing implementation in other countries.


A more recent example of an international harmonization initiative in the chemical industry is the cooperation of leading chemical companies in the World Business Council for Sustainable Development to publish a common approach for conducting Portfolio Sustainability Assessments (PSA). Companies engaged in developing the standard expect that harmonizing PSA approaches will increase the robustness and credibility of company efforts, building on leading best practices. Harmonization is also expected to reduce complexity for external stakeholders and enable consistency in communicating results, including the use of shared language on sustainability-related benefits and concerns throughout value chains and industries (WBCSD 2018). An example of private standard-setting in a downstream sector (the textile, leather and footwear industry sector) is the ZDHC initiative (see Part IV, Ch. 7).

A private sector harmonization initiative that cuts across industry sectors is the Proactive Alliance, which seeks to develop a common approach for collecting and sharing material data for articles (including their chemical composition) across sectors (Stringer 2018). This initiative addresses the fact that many sectors have their own material declaration systems, but currently do not communicate or share information between companies in different sectors despite many suppliers selling the same articles and components to multiple sectors. The automotive, chemicals, furniture, childcare products, electronics, mechanical, metalworking and metal articles, home textiles, textiles, sporting goods and medical devices sectors are among those engaged in the initiative.

### Opportunities to recognize and strengthen private standards under a beyond 2020 approach

Since stakeholders are negotiating an approach for chemicals and management beyond 2020, there may be value in exploring the extent to which private sector standard-setting could be encouraged, as well as how relevant initiatives by the chemical industry, or downstream industry sectors, could be recognized under a global approach, including monitoring of the progress made. If, as may be anticipated, a future global beyond 2020 approach continues to have a multi-sectoral and multi-stakeholder orientation, dialogue and consultation with civil society organizations have the potential to improve the robustness of the initiative and increase legitimacy. Of equal interest may be the question of how to scale up participation by stakeholders and industry in all regions of the world, with the goal that common and harmonized approaches will ultimately enjoy universal participation.

## 4.5 Regulatory decision-making drives innovation

### Lessons from international initiatives

The Montreal Protocol on Substances that Deplete the Ozone Layer, which came into force in 1989, is generally considered a very successful example of international environmental leadership (Canan *et al*. 2015). The prospect of international regulation of ozone-depleting substances offered DuPont, the world's dominant producer of chlorofluorocarbons (CFCs) up to the 1980s, the possibility of new and more profitable markets at a time when the production of CFCs was losing its profitability and promising alternatives had already been identified (Maxwell and Briscoe 1997). The company invested more than US dollars 500 million in developing and commercializing CFC alternatives and rapidly implemented new technologies (Rotman 2007; DuPont 2015).

Response to the Montreal Protocol illustrates the potential benefits of global policies that address the sound management of chemicals and waste by stimulating innovation, investment in research and development, awareness-raising and technology transfer. Since it entered into force, countries have continuously made efforts to take further steps and to address more ozone-depleting substances. International activities are being carried out to meet remaining challenges in reducing emissions of ozone-depleting substances while, at the same time, reducing emissions of greenhouse gases (GHGs). Replacing hydrofluorocarbons (HFCs), which are not ozone-depleting chemicals but have high global warming potential (GWP) values, will have additional benefits with respect to combating climate change (United States National Aeronautics and Space Administration 2015; UNEP 2016; US EPA 2016).

Innovative approaches adopted by governments and industry within the framework of the Montreal Protocol have resulted not only in a high rate of replacement of ozone-depleting GHGs by more environmentally friendly alternatives, but also in increased product efficiency (Eklund *et al.* 2013). Moreover, the regional networks of

National Ozone Units (government units in developing countries that are responsible for managing national programmes to comply with the Montreal Protocol) continue to strengthen regulatory action through fruitful collaboration among stakeholders (UNEP 2018).

### Lessons learned from national initiatives

Decision-making which foreshadows a transition towards the substitution of hazardous chemicals by safer chemical and non-chemical alternatives is a driving force for academia and industry to initiate research to develop such alternatives. In the EU and the United States (in states such as Washington, Maine and California) chemical management regulations require assessments of chemicals that are classified as being of priority or of very high concern in order to evaluate the potential for safe and feasible substitutions (Jacobs *et al.* 2015).

One study (EC 2015) has suggested that REACH registration requirements were a main driver behind an increasing focus on safer and more environmentally friendly chemicals in research and innovation. Other forms of innovation identified by private enterprises have included increased knowledge of chemical safety; awareness of needs upstream and downstream in value chains; and improved risk management procedures. Another study (Berrone *et al.* 2013) found that institutional pressures can trigger innovation, especially in companies which are relatively more polluting. These studies suggest that governments can stimulate innovation, leading to environmental improvements, by discussing their regulatory intentions at an early stage with stakeholders.

The Center for International Environmental Law examined the impacts in the EU and the United States of laws concerning hazardous chemicals in terms of innovation. It found that the prospect of stricter laws significantly sparked the invention, development and adoption of alternatives. For example, exponential growth in the number of patented inventions for alternatives to phthalates was identified from 1999 onwards, coinciding with the adoption of stricter measures concerning their use (Center for International Environmental Law 2013). On the other hand, very prescriptive, rigid regulation can hamper innovative activity by reducing the attractiveness of engaging in R&D, constraining modes of commercialization, and creating lock-in effects that require adherence to suboptimal standards (Pelkmans and Renda 2014).

## 4.6 What are the opportunities for moving forward on risk management decision-making?

### Recent developments concerning the burden of proof of chemical safety

In a significant number of countries chemicals management legislation has been established that requires industry to provide a certain amount of safety information about a chemical that has been (or is planned to be) placed on the market. Based on a judgement about whether there is unacceptable or unreasonable risk, authorities then determine whether the chemical is safe for the intended use, or whether more information or regulatory action is needed. Information gaps and uncertainties can, however, make it difficult for authorities to perform a complete science-based risk assessment (Lofstedt 2011).

A number of regulations have been updated. A recent comparative study of regulatory reforms in the EU and the United States (Botos, Graham and Illés 2018) describes the main drivers leading to updates in the regulation of industrial chemicals. In the EU, changes in the regulation of hazardous substances under REACH have focused on remedying the problems of lack of data on the safety of chemicals; the need to speed up prioritization and risk assessment/management tasks; and the need to implement the polluter pays principle. As early as 1997, discussions began on whether the burden of proof of safety could be reversed (Hansson 1997). This has occurred, for example, in the EU under REACH, which places the burden of proof on companies, requiring them to identify and manage the risks linked to the substances they manufacture and market in the EU. They must demonstrate how the substance can be safely used and communicate risk management measures to users (ECHA n.d. d). This type of approach reduces the resource burden for authorities by placing responsibility on companies. In particular, countries with limited resources may consider the option of developing or updating chemicals legislation, taking into account burden of proof considerations.

### Risk management decision-making based on generic considerations, hazard properties and impacts

Regulators often prefer to use risk assessments as the basis for developing, analyzing and comparing regulatory options, and for selecting and implementing the optimal decisions; thus, they can identify the instrument or mix of instruments that is best suited to help achieve the risk management objectives on a sustained basis (Government of Canada 2016; ECHA n.d. e). However, management decisions can also be based on the hazard and generic risk considerations discussed earlier, which may be simpler given that hazard information is an intrinsic chemical property about which information is globally accessible.

The classification of chemicals in GHS categories is based on hazardous properties. It is an example of hazard-based management. If a substance itself, or one in a mixture, has a specific hazard, the hazard should be communicated to users in order to alert them to the possible risks arising from its use. This helps to manage risks: for example, gloves might be worn in the case of substances that are skin irritants. It can also be argued that management action could be taken based on endocrine disruption or carcinogenic, mutagenic or reprotoxic (CMR) properties. A cancer hazard identified by the International Agency for Research on Cancer (IARC) gives regulators strong indications of necessary management action (IARC 2018).

A close look at chemicals legislation in which both hazard- and risk-based practices are considered (e.g. REACH) suggests that these approaches do not necessarily conflict. Instead, they can be seen as complementary means of informed decision-making (Hansen 2017). For example, guidelines for toxicity testing and the criteria for classification set an upper dose limit above which exposure can no longer be assumed to be reasonable and no testing is done; animal welfare is also a factor in this regard. This is described in the guidelines as the application of the "limit test". In addition, this information is used when deciding on whether to classify a substance. Within the EU chemicals management framework (for industrial chemicals, plant protection products, biocides, and classification, labelling and packaging [CLP]) "hazard-based" and "risk-based" approaches can be seen as based on the same principles.

Alternatively, there are also approaches for exposure-based priority-setting (Egeghy *et al.* 2011). In this context very persistent and very bioaccumulative properties can be drivers to consider action. In light of the often limited resources available for risk management, it might be useful to consider the extent to which less resource-intensive approaches (e.g. hazard-based ones) could accelerate decision-making regarding the sound management of chemicals. In this respect, it might be helpful to bring together the combined expertise of the Inter-Organization Programme for the Sound Management of

Chemicals (IOMC) (WHO 2018b) participating organizations and develop globally applicable guidance.

Risk management based on hazard assessment is advancing in the retail sector. Consumers increasingly demand safe and healthy products, as well as transparent information (e.g. about "food miles"). This has led many large retailers to consider offering "toxic-free" consumer products as being good for business. To that end, leading companies are initiating (and requiring from their suppliers) the use of hazard assessment approaches as a means to differentiate products and ingredients with lower versus higher hazards, or to certify "greener" chemical ingredients in their consumer products (Box 4.1). Hazard is therefore used as a basis to address consumer concerns about chemical safety and to manage the safety of products offered for sale by the retailers concerned.

### Using socio-economic assessment in decision-making

Socio-economic assessment (SEA) is used in a number of risk management decision-making processes. Many legislative frameworks for chemicals management request that it be used as an established method of weighing the pros and cons of an action for society as a whole when decisions are taken on management options. An SEA should be carried out in a transparent way, using distinct analytical parameters. It can add particular value when the benefits of regulation or pollution prevention can be calculated, and when the risk assessment includes specific exposure data as well as explicit conclusions from hazard identification and dose-response assessments (Chiu 2017) (Figure 4.2). The outcomes of an SEA can also be helpful in the communication and justification of actions, and in facilitating transparency in the decision-making process (OECD 2016). The ECHA and the US EPA have developed guidance for use in SEA (ECHA 2017; US EPA 2018).

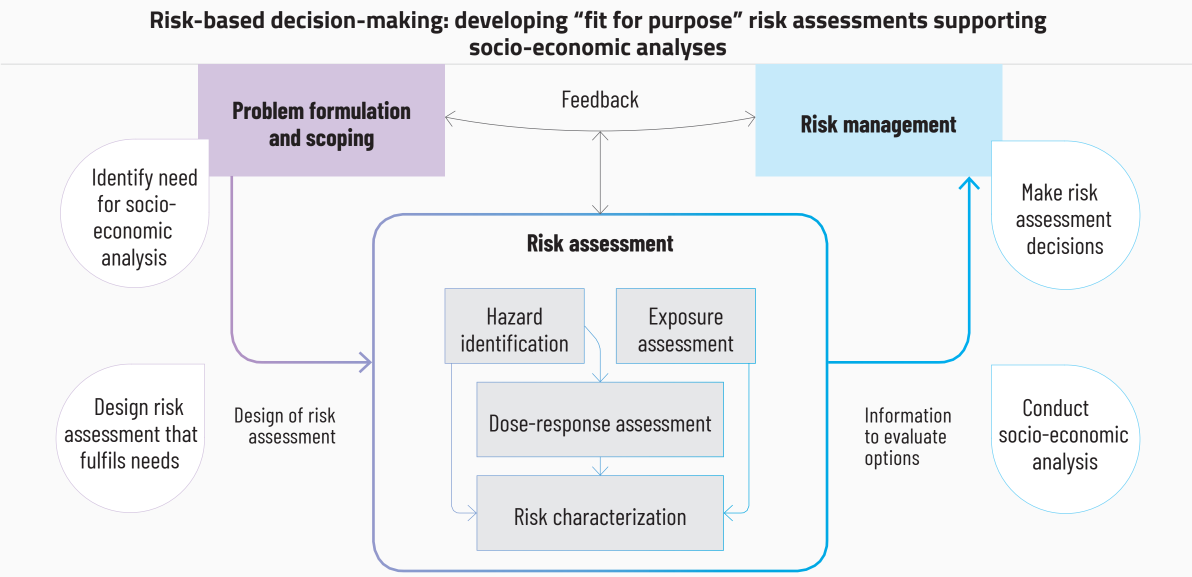
In recent years significant methodological progress has been made in assessing the costs and benefits of managing the risks of chemicals. Further work is required, particularly concerning the need to obtain better information to evaluate the benefits for human health and the environment of possible regulatory action. For example, when information is available, opportunities to better support SEA include providing population variability estimates in exposure assessment; using more formal approaches in evaluating the evidence for causal relations between exposure and specific effects; and applying probabilistic methodologies to make predictions of dose-response (Chiu 2017).

For environmental policy decision-making, cost-benefit analysis can be used to consider the case for the (social) efficiency of decisions within the broader policy process. This would involve understanding what the decision options provide in terms of benefits (defined as increases of human well-being) and costs

**Box 4.1** **Tools used by retailers to identify hazardous chemicals in their products and to select safer and greener alternatives**

Many tools exist to assist companies in finding safer and greener chemicals to use in their supply chains. One example is the much-used GreenScreen®, a globally recognized tool that identifies hazardous chemicals and safer alternatives (GreenScreen 2018). The Chemical Footprint Project (CFP) is an initiative of investors, retailers, government agencies, non-governmental organizations (NGOs) and health care organizations that aspire to support healthy lives, clean water and air, and sustainable consumption and production through the effective management of chemicals in products and supply chains (Rossi *et al*. 2017). The Green Chemistry and Commerce Council (GC3) is a multi-stakeholder collaborative that drives the commercial adoption of green chemistry through catalysing and guiding actions across all industries, sectors and supply chains (GC3 n.d.). Various organizations, including retailers and business groups, often use a suite of tools to evaluate chemicals in products These have been listed and reviewed by Gauthier *et al.* (2014) and Panko *et al.* (2017).

**Figure 4.2** Risk assessment and socio-economic assessment (SEA) (adapted from Chiu 2017, p. 11)




(defined as reductions of human well-being) (Atkinson *et al*. 2018). Such cost-benefit analysis could be improved when countries have clear legislative requirements for its use and its role in the decision-making context, and when clear decision-making rules are in place that are transparently communicated. Proposals for marketing restriction usually need to contain a description of the risks, as well as information on health and environmental benefits, associated costs, and other socio-economic impacts. Such analysis is also important for policymakers in justifying the value of investing public funds in a chemical management system. There is an ongoing OECD project on the Socio-economic Analysis of Chemicals by Allowing a better quantification and monetization of Morbidity and Environmental impacts (SACAME). Several case studies and analyses have been developed to help counties advance in this field (OECD 2018b). Cooperative action by countries would allow mutual learning about the practical application of SEA methodologies and enable their further development from an applied perspective (OECD 2016).

SEA can also be important in decision-making on the risk management of chemicals in developing countries. A holistic and quantitative SEA case study, using a developing country-specific SEA framework and similar methodology, was applied in China in the phase-out of hexabromocyclododecane (HBCD), a brominated flame retardant, under the Stockholm Convention on Persistent Organic Pollutants (POPs) (Zhu *et al.* 2016).

## Use of market-based instruments in chemical risk management

An analysis of pesticide tax schemes in several European countries examined the importance of applying market-based instruments to reduce risks in agricultural systems (Böcker and Finger 2016). For the countries being compared it was found that even if the effectiveness of pesticide taxes appeared to be limited, a high enough tax on a specific pesticide would significantly reduce its application and the associated risks. In Sweden, for example, a simple, fixed tax scheme has been used since the 1980s. A tax on the use of pesticides was introduced in Denmark in 1965; since 2013 this tax has been based on environmental load (Pedersen 2016). A number of other European countries have also implemented pesticide levies or taxes. When there are adequate economic, political and environmental conditions, a highly differentiated tax scheme is potentially an effective instrument in the long term to reduce the load of hazardous pesticides and contribute to Integrated Pest

Management (IPM) (see also Part IV, Ch. 5 for fiscal incentives and market-based instruments).

Market-based instruments can be used in combination with command and control regulatory measures (e.g. prohibitions or restrictions) by accelerating the phase-in of alternatives during a transition phase until a substance is prohibited. While the use of market-based instruments in advancing the management of hazardous chemicals and waste is still limited, it has the potential to increase. Financial institutions can also help advance chemical safety. With respect to financing, the International Finance Corporation has a Sustainability Framework which includes performance standards applied to all investments and clients whose projects undergo a credit review process (International Finance Corporation 2012). In another context, a particular challenge emerges in reforming subsidy programmes that are creating incentives to use chemicals (e.g. increasing use of fertilizers to boost agricultural production) (Tan 2005; Bartelings *et al.* 2016).

### What are the challenges and opportunities for countries with limited resources?

Effective implementation of risk management instruments and measures differs among countries, depending to a large extent on the amount of resources that can be made available to put the necessary structures in place (OECD 2015). Countries with limited capacities and resources face important challenges in setting up chemicals management programmes (Wang *et al.* 2016). For example, a study carried out in Tanzania (Stockholm Environment Institute [SEI] 2014) found that significant problems related to misuse of chemicals in the agricultural sector, wood preservation and small-scale mining persisted. It reported that an institutional issue to be tackled was improving national coordination.

In addition to the success story of the Montreal Protocol, the Basel, Rotterdam and Stockholm Conventions have provided important support to national governments and other stakeholders through scientific and technical guidance to address certain industrial chemicals, pesticides and their associated wastes. Not only has the implementation of these Conventions led to a number of concrete global risk management actions. They have also been instrumental in strengthening national capacities for risk management. Implementation of the Minamata Convention is expected to provide additional benefits (see Part I, Ch. 8).

Countries with limited resources for risk management may consider starting with the implementation of the GHS and then making this part of an overall national chemicals strategy, rather than a stand-alone project. The development of the legislation needed for GHS implementation involves many sectors. Therefore, the multi-stakeholder platform created could serve as a basis for further discussions on chemical risk management. Concretely linking GHS implementation to the 2030 Agenda for Sustainable Development could also increase political support for chemical management at the national level (SEI 2017).

UNEP's Guidance on the Development of Legal and Institutional Infrastructures and Measures for Recovering Costs of National Administration for Sound Management of Chemicals (known as the LIRA Guidance) aims to provide practical support to policymakers to strengthen national legislation and institutional arrangements for achieving sound management of chemicals. The main objective of LIRA is to support countries in the process of developing national plans for strengthening legal and institutional infrastructures to govern the placing of chemicals on the market as part of a life cycle chemicals management policy. It includes proposals for measures to finance necessary administrative activities in this regard (UNEP 2015).

The IOMC Toolbox for Decision-making in Chemicals Management, which is internet-based, enables countries to identify the most appropriate and efficient actions to solve specific national problems related to chemicals management (Box 4.2). The Toolbox guides users towards cost-effective solutions which can be adapted to a particular country. It presents relevant IOMC resources, guidance documents and training material, all of which are available online and free of charge. In the Toolbox there are currently

**Box 4.2** **Decision-making for industrial chemicals: the IOMC Toolbox**


The IOMC Toolbox (https://iomctoolbox.oecd.org/) identifies appropriate actions and guidance for the following:

- a national management scheme for pesticides;
- an occupational health and safety system;
- a chemical accident prevention, preparedness, and response system for major hazards;
- an industrial chemicals management system;
- a classification and labelling system;
- a system to support health authorities in the public health management of chemicals; and
- Pollutant Release and Transfer Registers.

The Toolbox also provides links to the following five new online toolkits:

- the OECD Environmental Risk Assessment Toolkit;
- the WHO Human Health Risk Assessment Toolkit;
- the FAO Toolkit for Pesticides Registration Decision Making;
- the UNIDO Toolkit on Chemical Leasing; and
- the UNIDO Toolkit on Innovative, Safe and Resource Efficient Application of Chemicals in Industry.

seven management objectives that can be selected (OECD 2018c). For each management objective, options requiring limited, medium and high levels of resources are included. The Toolbox also provides interactive features allowing governments to use it as a platform for collaboration among ministries, agencies, and other stakeholders such as industry.

## 4.7 Potential measures to further advance risk management decision-making

Countries could cooperate further to facilitate the use of more efficient chemical risk management approaches in countries that have limited resources, including through full implementation of the GHS, which would provide a basis for risk management decision-making in all countries. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance risk management decision-making:

- Improve access to (and understanding of) chemical hazard, exposure and risk information by relevant stakeholders, including workers and consumers.
- Increase international cooperation in order to facilitate worldwide implementation of the GHS, and explore the importance of GHS implementation for relevant SDG targets.
- Refine and scale up the use of socio-economic analysis in risk management decision-making, including for application in developing countries.
- Promote voluntary risk management initiatives to complement regulatory measures.
- Evaluate the need to strengthen risk management approaches in line with national priorities.
- Further develop innovative regulatory approaches to drive innovation to design safer chemicals.

# 5/ Assessment of chemical and non-chemical alternatives: focusing on solutions

## Chapter Highlights

Regulatory actions, public pressure and voluntary initiatives drive the identification, evaluation and adoption of safer alternatives to chemicals of concern, in both products and processes.

Conventional approaches focus on reducing exposure to an acceptable level and evaluating drop-in replacements. Replacements often are of the same chemical class and have the same hazards.

Informed substitution aims to provide a safer functional match, including non-chemical alternatives, either through chemical replacement or through a process or technological change.

Alternatives assessments aim to focus on solutions and provide information to avoid regrettable substitutions, as well as to transition to more sustainable chemicals, materials, products and practices, often incorporating holistic sustainability assessment and life cycle thinking.

Challenges to robust assessment of alternatives, and the adoption of substitutes, include a lack of supportive policies, insufficiently mature methodologies, data gaps and limited experience

Chemical alternatives assessment has emerged as an important dimension of chemical risk management. It is a forward-looking and problem-solving means of identifying, evaluating and adopting safer alternatives to hazardous chemicals in products and processes. Safer alternatives can include safer chemicals and non-chemical alternatives, as well as changes in process, design and systems that lead to the informed substitution of chemicals of concern. This chapter introduces the latest developments in chemical alternatives assessment approaches; discusses how informed substitution of hazardous chemicals by safer alternatives can be an efficient and effective means of managing chemical risks; and identifies opportunities for future action.

## 5.1 What are the drivers for evaluating and adopting safer alternatives?

### Momentum is increasing to remove chemicals of concern from processes and products

Both regulatory and non-regulatory drivers are providing momentum for the removal of chemicals of concern from manufacturing processes and from products. Non-regulatory drivers, such as consumer concerns, and pressures from NGOs (e.g. Greenpeace's global campaign focusing on toxic chemicals in the textile industry) have stimulated market demand for the removal of toxic chemicals in a wide variety of consumer product sectors (Grappi, Romani and Barbarossa 2017; Hartmann and Klaschka 2017; Greenpeace International 2018). A number of large retailers, including Walmart, Target and The Home Depot in the United States, have announced strategies to reduce the presence of chemicals of concern in the products they sell (Brown-West 2017; MacCarthy 2017; Sturcken 2017; United States Natural Resources Defense Council 2018; Walmart 2018). How government action and regulatory substitution goals can encourage voluntary initiatives is addressed in Part III, Ch. 4.

A number of regulatory programmes, including in the EU and the State of California in the United States, require that manufacturers conduct alternatives assessments for chemicals of high concern (EC 2006; State of California Department of Toxic Substances Control [California DTSC] 2009; California DTSC 2017). At the international level, treaties such as the Montreal Protocol on Substances that Deplete the Ozone Layer and the Stockholm Convention on Persistent Organic Pollutants have specific provisions for the analysis of alternatives that could be substituted. These treaties provide critical stimuli for substitution by countries and global corporations (see also section 5.4 below).

## 5.2 Informed substitution: a critical chemical risk management approach

### From conventional risk management to informed and functional substitution

In conventional chemical risk management strategies, it is typically assumed that use of a toxic chemical is a given. Consequently, these strategies often focus on controlling exposure to an acceptable level, as informed by risk assessments. Many chemical substitutions to date have focused primarily on individual chemicals, chemical classes or product types rather than on the functional uses of chemicals (e.g. as solvents, preservatives, surfactants or flame retardants). Although policies focused on substitution may consider chemical function, or functional use, in order to frame the technical evaluation of alternatives, the concept of functional use has not traditionally been used as a basis for policy (US NRC 2014).

The goal of informed substitution is to replace a chemical with a functional match (one which is

© USAID/John Healey, Ruth Mushinge prepares her mosquito net in her home near Mundabi, Zambia

**Table 5.1** A functional substitution approach for chemicals in products and processes (Tickner *et al.* 2015, p. 744)

| Functional substitution level | Chemical in product<br>Bisphenol A in thermal paper | Chemical in process<br>Methylene chloride in degreasing metal parts |
|---|---|---|
| **Chemical function**<br>(Chemical change) | Is there a functionally equivalent chemical substitute (i.e. chemical developer)?<br>**Result: Drop-in chemical replacement** | Is there a functionally equivalent chemical substitute (i.e. chlorinated solvent degreaser)?<br>**Result: Drop-in chemical replacement** |
| **End Use function**<br>(Material, product, process change) | Is there another means to achieve the function of the chemical in the product (i.e. creation of printed image)?<br>**Result: Redesign of thermal paper, material changes** | Is there another means to achieve the function of the process (i.e. degreasing)?<br>**Result: Redesign of the process (e.g. ultrasonic, aqueous)** |
| **Function as service**<br>(System change) | Are cash register receipts necessary? Are there alternatives that could achieve the same purpose (i.e. providing a record of sale to a consumer)?<br>**Result: Alternative printing systems (e.g. electronic receipts)** | Is degreasing metal parts necessary? Are there alternatives that could achieve the same purpose (i.e. providing metal parts free of contaminants for other end uses)?<br>**Result: Alternative metal cutting methods** |

safer for humans and the environment) through chemical replacement, or through a process or technological change that can eliminate the use of that chemical. Informed substitution employs a systematic process that uses the best available information to make choices about substitutes (Lavoie *et al.* 2010; US NRC 2014). It assumes that the function of a toxic chemical can be carried out using a safer option, which could be a different chemical or a completely different technology. In a given application it is the function provided by a chemical that is needed, not necessarily the chemical itself. Considering chemical function, rather than simply comparing the risks of drop-in chemical alternatives, offers a means of identifying a broad range of options to meet a particular functional need: this is referred to as "functional substitution" (Table 5.1).

When safer options are not available, research can be undertaken to investigate the use of safer chemistries (e.g. green or sustainable chemistry; see Part IV, Ch. 1) or to develop engineering or design solutions. This is consistent with the precautionary principle, the source reduction approach inherent in cleaner production and in the industrial hygiene hierarchy of controls – concepts that evolved in the 1990s (O'Brien 2000; Ashford 2013).

A functional substitution approach also makes it possible to open up to broader societal considerations, including whether a given function is needed or whether the technical requirements for a function are too stringent. An example is the current debate about flame retardancy standards, and whether those standards that require the addition of chemical flame retardants are necessary to meet fire protection goals (Babrauskas *et al.* 2012; Israel 2013; State of California Department of Consumer Affairs 2014; Baker 2018). Special considerations might apply to pesticides. Social and cultural characteristics and long-term economic and environmental sustainability are important aspects of alternatives assessment in this case. Here it is not just a question of replacing one chemical with another, as it might be in an industrial process. The consideration of agroecology-based alternatives for highly hazardous pesticides was emphasized at the fourth session of the International Conference on Chemicals Management (Secretariat of the Strategic Approach to International Chemicals Management 2015).

## Alternatives assessment

Alternatives assessment has emerged as a preferred process to support informed substitution. It is an iterative, step-defined and solutions-oriented process for identifying and comparing potential chemical and non-chemical alternatives that could replace chemicals of concern on the basis of their hazards, performance and economic viability

**Table 5.2** Components of an alternatives assessment (US NRC 2014; Geiser *et al.* 2015)

| Component | What it involves |
|---|---|
| Scoping, problem formulation, identifying alternatives for consideration | Establishes the scope of (and plan for) the assessment; identifies stakeholders to be engaged and decision rules that will guide the assessment; gathers data on the chemical of concern, its function and application; determines assessment methods and identifies alternatives to be considered. |
| Hazard/comparative exposure assessment | Evaluates human health and environmental hazards and assesses comparative exposures. |
| Hazard/comparative exposure assessment | Assesses the performance of alternatives against the requirements established during the problem formulation step above. |
| Economic feasibility assessment | Assesses the economic feasibility of alternatives against the requirements established during the problem formulation step above. |
| Other life cycle considerations | Addresses additional factors critical for determining risks to human health and the environment beyond those included in the hazard/exposure assessment component to avoid risk trade-offs (e.g. energy, climate change impacts). |
| Decision-making | Identifies acceptable alternatives based on information compiled in previous steps. Addresses situations where no alternatives are currently viable by initiating R&D to develop new alternatives, or improve existing ones, and establishes an implementation and adoption plan to identify potential trade-offs during adoption. |

(US NRC 2014; Geiser *et al.* 2015) (Table 5.2). Alternatives assessment is used to provide critical information, in a systematic and continuous-improvement manner, that informs the choice of alternatives, guiding the transition to safer chemicals, materials and processes and reducing the potential for regrettable substitutions. This is similar to the planning approach that is central to cleaner production and pollution prevention. The six general steps for alternatives assessments are shown in Table 5.2. Alternatives assessments may include modifications to how a product is engineered or used or explore non-chemical alternatives, thereby shifting the focus from problem analysis to innovations and solutions (Geiser *et al.* 2015).

Alternatives assessment can be less or more complex, depending on the technical capacity of the user. For example, the United States Occupational Safety and Health Administration created a "Transitioning to Safer Chemicals" website and capacity training to support small and medium-sized enterprises (SMEs) in making informed choices about chemical alternatives. The goal was to instil systematic thinking about alternatives at the firm level in a relatively simple manner, providing resources for firms to make informed decisions and understand potential trade-offs in choices (US OSHA n.d.).

There is little documentation on policy experience with alternatives assessment or with substitution. This makes drawing general conclusions on best practices a challenge, and may reflect hesitation by corporations to share potentially proprietary chemical information (Tickner and Jacobs 2016). The EU Substitution Portal SUBSPORT (SUBSPORT n.d.) and the OECD Substitution and Alternatives Assessment Toolbox (OECD n.d.) present experiences with chemical substitutions that are publicly available. These initiatives are a good basis for the collection of further experiences.

### Frameworks for alternatives assessment

How potential alternatives are identified, screened for and evaluated in an alternatives assessment is guided by the choice of the framework followed. In this context a framework can be considered as the linear – and sometimes iterative – steps recommended to guide the implementation of an alternatives assessment. As discussed in a recent review of alternatives assessment frameworks published during the last two decades (Jacobs *et al.* 2015; OECD n.d.), some frameworks are issued by regulatory authorities, such as the ECHA and the State of California, and need to be followed if the alternatives assessment is being conducted for compliance purposes. Other frameworks are primarily guidance documents developed to better inform voluntary or regulatory assessment efforts. Some frameworks are more comprehensive than others regarding suggested methods and the attributes included (including toxicological endpoints and life cycle considerations); however, the majority follow the basic structure outlined in Table 5.2 (Jacobs *et al.* 2015).

All the alternatives assessment frameworks identified share a common purpose, namely to identify a safer alternative based on a comparative assessment of hazard characteristics as well as technical and economic feasibility (Geiser *et al.* 2015; Jacobs *et al.* 2015). These frameworks require greater consistency in the methods used, as well as in the minimum steps and the level of types of data required. Consistent methods and data requirements will help support transferability of assessments from one region to another; they will also strengthen alternatives assessment as a preferred approach to addressing problem chemicals (Jacobs *et al.* 2015). However, the field of alternatives assessment is young. Gaps in methodologies, and a lack of consistent standardization and understanding of best practices across regions, can hinder global actions towards effective substitution (Tickner *et al*. 2018). To understand challenges and success factors, capacity building needs and best practices, there is an urgent need for case studies of alternatives assessment, and of informed substitution/adoption experiences in a variety of contexts (e.g. small businesses, agriculture, institutional settings and large manufacturing companies).

### Common principles and criteria

Experts have noted that flexibility in the choice of an alternatives assessment framework is useful, as the substitution context can vary greatly, for example depending on toxicological assessment capacity (Geiser *et al.* 2015). However, increased consistency and standardization are necessary in the alternatives assessment field (Jacobs *et al*. 2015; Tickner *et al*. 2018). At the international level governments and other stakeholders could establish clearer, consistent criteria for safer and less-safe chemicals and provide guidance on minimum and preferred components and attributes to be included in an alternatives assessment, creating a means to evaluate the comprehensiveness and quality of assessments. In addition, criteria for efficacy testing of non-chemical alternatives would be important in regard to substituting harmful chemicals by non-chemical alternatives. Such criteria still need to be developed.

Data gaps (e.g. on chemical identity in a formulation, toxicity, end-of-life) are a persistent challenge for alternatives assessment (Tickner *et al.* 2018). Rather than ignoring data gaps, some alternatives assessment methods make data gaps explicit or eliminate data-poor alternatives from consideration, which allows more transparent decisions and helps identify research needs. For example, in the hazard assessment component of an alternatives assessment, the GreenScreen® hazard assessment method that is used in multiple alternatives assessment frameworks has a “data gap” classification for endpoints where there is insufficient information to assess the hazard (Clean Production Action 2017). This classification is considered in the overall gradings (“benchmarks” in the GreenScreen® method), often resulting in a lower overall score (i.e. more cautious about hazard).

As in risk assessment, transparency in the assumptions made and how data gaps are addressed is essential to alternatives assessment, allowing stakeholder discussion about the best means to address a particular chemical function. The iterative process and the continuous improvement nature of alternatives assessment require periodic updating of assessments as new information becomes available.

Despite the number of alternatives assessment frameworks available, the variety of decision contexts under which alternatives assessments occur and the ever-present issue of data gaps, the process can ultimately be guided by the Commons Principles for Alternatives Assessment (Toxics Use Reduction Institute [TURI] 2013). These Principles (to which the names of a diverse group of over 100 signatories from academia, industry and the NGO community are attached) have been designed to guide a process for well-informed decision-making that supports the successful phase-out of hazardous products, the phase-in of safer substitutes, and the elimination of hazardous chemicals where possible. The Commons Principles are: reduce hazard; minimize exposure; use the best available information; require disclosure and transparency; resolve trade-offs; and take action.

### The need to consider all three dimensions of sustainable development and life cycle aspects

A yet broader approach is essential when carrying out alternatives assessments, thereby giving attention to all three dimensions of sustainable development. Taking holistic account of social, environmental and economic considerations when evaluating potential alternatives can help identify trade-offs that might occur during the life cycle of a chemical or product as a result of substitution. The case of dental amalgam illustrates the challenges associated with the dimensions to be considered in substitution (Box 5.1).

Life cycle thinking (LCT) and, where needed, life cycle assessment (LCA) can be important components of risk management, particularly for chemical-to-process or material substitutions in alternatives assessment. LCA is a valuable tool to accompany alternatives assessment. Its efficient and effective implementation can drive innovation and diffusion of safer alternatives (Sinsheimer 2010) and identify potential trade-offs to be addressed. A life cycle approach identifies the stages of a product over its entire life cycle and potential environmental, social and economic impacts. These include raw material extraction and energy transformation through production, packaging, distribution, use, maintenance, and eventually recycling, reuse, recovery or final disposal at the end of life. LCT enables product designers, service providers, government agencies and individuals to make choices for the longer term with consideration of all environmental impacts. UN Environment hosts a Life Cycle Initiative (UNEP 2017).

**Box 5.1** **Dental amalgam – informed substitution in developing countries (UNEP and WHO 2014; UNEP 2016; Fisher *et al.* 2018)**

Dental amalgam is a combination of metals with around 50 per cent mercury. It has been used for dental restoration during the last 150 years because of its mechanical properties and dentists' long-term familiarity with its use. Amalgam can also be a source of mercury pollution, particularly in municipal wastewater. Nevertheless, it is cheaper than other solutions for patients in many countries and has advantages compared with some alternatives (e.g. composite, glass ionomer, compomer and ceramic). Insufficient systematic studies have been undertaken regarding the ecotoxicity, as well as broader social and economic issues, related to various alternatives. Adding to this complexity, local conditions in developing countries may make the replacement of amalgam challenging, for example due to lack of a reliable water and electricity supply, which is needed when using resin-based composites (Fisher *et al*. 2018).

Many countries are phasing down (rather than phasing out) the use of amalgam, applying a stepwise and gradual approach as called for by the Minamata Convention on Mercury. This approach was taken during the East Africa Dental Amalgam Phase Down Project, which was implemented in Kenya, Tanzania and Uganda. That project included the involvement of (and consultations with) dentists and dental associations, implementation of awareness-raising activities for patients and doctors, modification of existing regulations, and improvement of dental insurance schemes. As foreseen in the Minamata Convention, measures to phase down the use of amalgam need to be multi-faceted, including setting national objectives aimed at dental caries prevention to reduce the need for dental restoration; training of dental professionals; and encouraging insurance policies that favour the use of alternatives.

© David DeKunder, Department head and research dentist, demonstrates how an amalgam separator is attached to a dental chair and how it works in removing amalgam waste to prevent it from going into the wastewater system.

In California, the Department of Toxic Substances Control requires that LCA tools be taken into account in evaluating potential alternatives. In this context, it is suggested that such an evaluation would build on an alternatives assessment and include identification of the life cycle attributes of potential concern (California DTSC 2009). These could include critical trade-offs between various alternatives and weighing the importance of different chemical attributes (e.g. cancer vs. endocrine disruption) and criteria (e.g. health vs. cost) as considerations in determining the best alternatives (Sinsheimer 2010).

There are a number of practical challenges related to the full application of LCA in alternatives assessment, (e.g. concerning data availability), while a number of methodological issues require attention (Fantke and Ernstoff 2018). The robust, sustainable and credible use of LCA needs to avoid over-interpretation of LCA results without proper consideration of its gaps and limitations. Challenges and gaps in the methodology represent research needs for the scientific LCA community that could inspire further progress in method development (Finkbeiner *et al*. 2014). When conducting alternatives assessment, experts have recommended targeting those life cycle stages and impact categories that are comparatively different for the chemical of concern and the alternatives being considered in order to streamline and target LCA needs in the assessment (Tickner *et al.* 2018).

## 5.3 Strengths and weaknesses of existing alternatives assessment approaches

### Informed substitution is an efficient and effective means of managing chemical risks

The process of "functional substitution" also reorients chemicals management approaches from time-intensive risk assessment, and risk management based on single chemical substances, to comparative evaluations of the best options to fulfil a specific function. This includes considering the necessity (or technical requirements) for the function in the first place. While the concept of function may not be a key consideration in chemicals assessment and management today, chemists and designers regularly focus on function when identifying cost-effective, high-performing options for a particular product or manufacturing process (Tickner *et al.* 2015).

Substituting hazardous chemicals with safer alternatives reduces the need for complex engineering controls, safety systems, personal protective equipment, and collection and monitoring schemes that can be costly and have the potential to fail. However, despite the fact that informed substitution supports efficient risk management strategies, an alternatives assessment is not often included within the structure of typical governmental risk management programmes (Tickner *et al.* 2013).

### Substitution as an innovation driver

Framing substitution as an issue of innovation, rather than compliance, could help to scale up the application of substitution (ECHA 2018). Chemical substitution efforts often focus on removing the chemical of concern, but not on the transition

**Box 5.2 Proactive substitution by frontrunners: safer alternatives for brominated flame retardants in the electronics sector (Wendschlag 2015)**

Hewlett Packard (HP) is among the companies in the electronics sector that face continued regulatory and consumer pressure to remove hazardous substances of concern from electronic and electrical products. Brominated flame retardants are one class of toxic chemicals in electronics that carries risk across all product life cycle stages: during production, use and disposal. They are among the six substances restricted under the EU RoHS (Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment) Directive, and also regulated under the Stockholm Convention. The increasing number of regulations and standards around the world that cover the electronics industry stimulated HP to evolve its chemical substitution approach.

To identify safer alternatives, HP created its Integrated Alternatives Assessment Protocol, which uses tools such as GreenScreen® to comprehensively assess the hazard profile of potential alternatives, as well as life cycle assessment tools to address the broader range of potential life cycle impacts. In its evaluation of 45 potential substitutes, HP identified roughly a dozen safer alternatives and subsequently worked with its suppliers to incorporate these substitutes into its products.

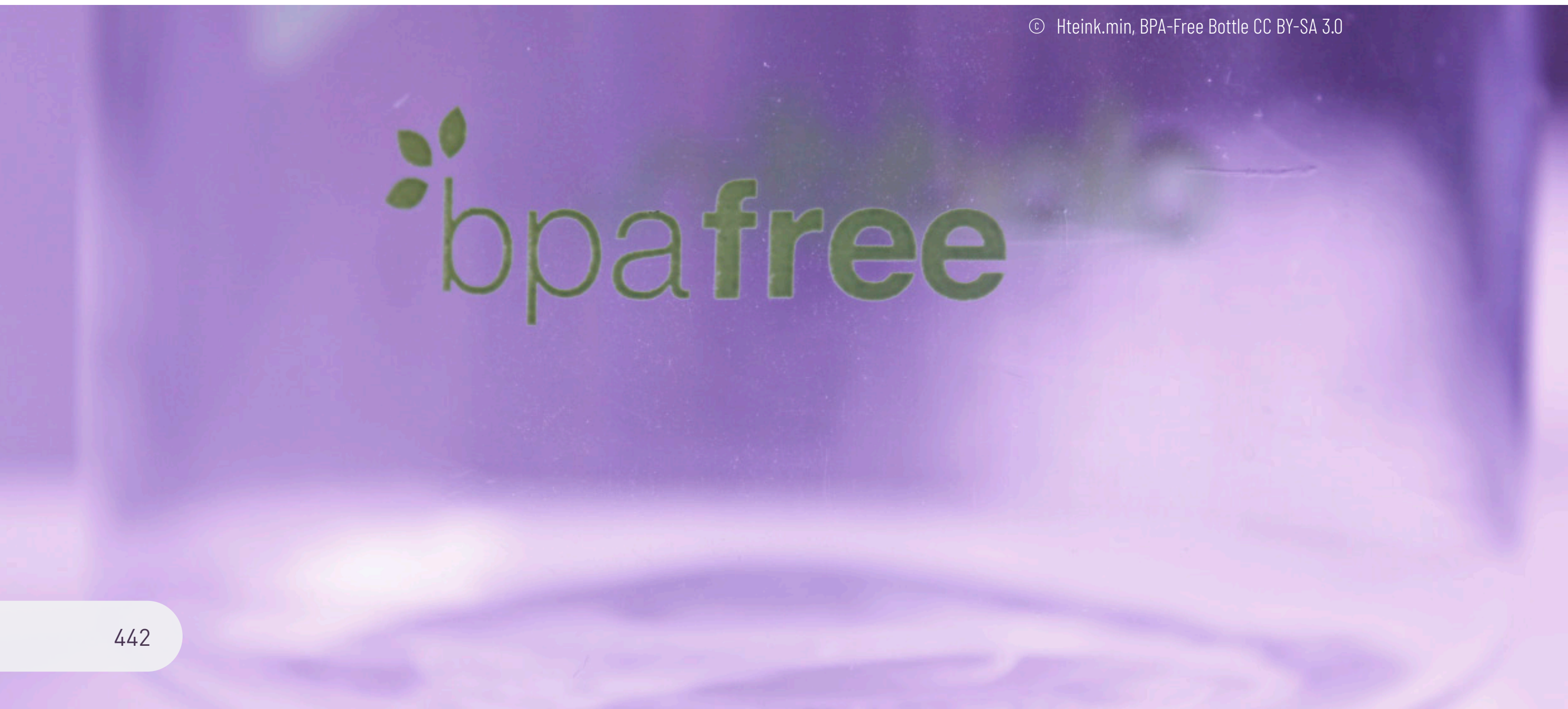


**Table 5.3** Examples in the literature referring to potential regrettable substitution (Siddiqi, Laessig and Reed 2003; US CDC 2008; Birnbaum and Bergman 2010; US NTP 2011; Ichihara *et al.* 2012; ECHA 2013; Tomar, Budroe and Cendak 2013; Eladak *et al.* 2015; Rochester and Bolden 2015; Canadian Centre for Occupational Health and Safety 2017; Anastas, Constable and Jiménez-González 2018; Jamarani *et al.* 2018; Sackmann *et al.* 2018)

| Chemical of concern (function) | Hazard of chemical of concern | Substitute | Hazard of substitute |
|---|---|---|---|
| **BPA** (used in production of plastics) | Endocrine disruption | BPS, Bisphenol F | Endocrine activity |
| **DEHP** (plasticizer) | Endocrine disruption | Diisononyl phthalate | Carcinogenicity, possible endocrine disruption |
| **Methylene chloride** (solvent carrier in adhesives) | Acute toxicity, carcinogenicity | 1-Bromopropane (nPB) | Carcinogenicity, neurotoxicity |
| **Methylene chloride** (brake cleaners) | Acute toxicity, carcinogenicity | n-Hexane | Neurotoxicity |
| **Polybrominated diphenyl ethers** (flame retardant) | Persistence, neurotoxicity, reproductive toxicity, carcinogenicity (penta and deca) | Tris (2,3-dibromopropyl) phosphate | Carcinogenicity, aquatic toxicity |
| **TCE** (metal degreasing) | Carcinogenicity | nPB | Neurotoxicity, carcinogenicity |

to safer chemistry or technologies. Redefining substitution as potential for innovation – rather than as a tool for removing and replacing problem chemicals – is therefore critical to the development of technologies that will help mitigate the current problem of toxic chemicals in the global chemical supply chain (Box 5.2).

## Insufficient evaluation of potential alternatives may result in regrettable substitutions

Chemical substitution without adequate consideration of the function of the chemical, and the advantages and disadvantages of alternatives for meeting that function, can result in a regrettable substitution. A regrettable substitution is one in which the alternative turns out either to have an unexpected hazard that results in similar or worse toxicity than the chemical of concern, or to involve shifting the burden of a hazard to another entity. For example, an alternative may no longer be carcinogenic compared to the chemical of concern, but be toxic to aquatic organisms. Alternatives assessments are an attempt to reduce the likelihood of regrettable substitutions by ensuring that hazards and exposure potential are considered alongside issues of performance and cost (Hogue 2013). Substitution should clearly take place when safer alternatives exist; it could also be the case, however, that alternatives are not totally harmless. A shift can be made to a safer alternative at the same time that research continues to find an even safer alternative solution.

Examples of regrettable substitutes include the replacement of polybrominated diphenyl ethers with tris (2,3-dibromopropyl) phosphate (TDBPP or brominated "Tris") (Siddiqi, Laessig and Reed 2003; Birnbaum and Bergman 2010); the replacement of bisphenol A with bisphenol S (Eladak *et al.* 2015; Harney *et al.* 2003; Rochester and Bolden 2015); and the replacement of trichloroethylene and methylene chloride with 1-bromopropane (Chao and Henshaw 2003; US CDC 2008; US NTP 2011; Ichihara *et al.* 2012) (Table 5.3).

Conducting an alternatives assessment will not completely eliminate the potential for adopting alternatives that could negatively affect human health or the environment. However, concerns about problematic substitutions or missing data – or fear of "paralysis by analysis" – should not be used as a reason not to substitute. Taking

**Box 5.3** **Replacing highly hazardous pesticides through Integrated Pest Management and non-chemical alternatives**

© Simon Kovacic/Shutterstock, Gardening with circular planting beds, a typical feature of permaculture

A number of countries have undertaken successful initiatives to reduce the use of highly hazardous pesticides (HHPs) by relying on Integrated Pest Management (IPM), an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides, including through the use of non-chemical alternatives.

One success story is Cuba. Eliminating the use of a pesticide was not seen as a simple substitution of inputs; instead changes in the management of agroecosystems have been introduced. This has included the use of biological agents, cultural changes, and focused application of other pesticides to phase out endosulfan (González 2016). The case of Cuba illustrates the concept of a broader functional approach where a non-chemical alternative as part of a broader IPM approach provides an alternative. Endosulfan has been used as insecticide on a global scale for vegetable and fruit crops, vineyards, cereals, coffee, tea, tobacco and cotton, among others. This HHP has caused fatal poisonings, accumulates in the fatty tissues of humans and animals and in breast milk, and is a possible endocrine disruptor. Endosulfan is included in Annex A (Elimination) of the Stockholm Convention and in the Rotterdam Convention. When endosulfan was listed under the Stockholm Convention in 2011, the Conference of the Parties (COP) asked the POPs Review Committee to assess both chemical and non-chemical alternatives. On the basis of this assessment, the Committee recommended, and the following (sixth) COP in 2013 endorsed, the recommendation that when replacing endosulfan, priority should be given to ecosystem-based approaches to pest control (Persistent Organic Pollutants Review Committee 2012; Secretariat of the Stockholm Convention on Persistent Organic Pollutants 2013).

IPM also provided the basis for a successful effort in the context of a SAICM Quick Start Programme project to phase out HHPs in Costa Rica and replace it with alternative pest management options, with a preference for non-chemical methods. Among others, the project found that there was no significant difference in roundworms infestation in pineapple production when using safer, non-chemical methods (such as commercial biopesticides and "wood vinegar") as opposed to HHPs, while at the same time harmful side effects were reduced. As regards coffee production, trials found the combination of one or more non-chemical alternatives with reduced-rate application of non-HHP fungicides to be a feasible and affordable option (Pesticide Action Network UK 2017).

a broader functional substitution approach by considering non-chemical alternatives can provide effective means of avoiding regrettable substitutions that could occur as a result of chemical-by-chemical drop-in substitution approaches (Table 5.3).

The conventional pesticide industry and market have undergone major changes in recent decades, resulting in greater efficiency of pesticide use than in the past through major improvements to pest management technology and practices in the context of IPM programmes. In this context, biopesticides (natural materials derived from animals, plants, bacteria and certain minerals) are used in pest control. Currently, biopesticides account for 5 per cent of the total crop protection market globally with a value of about US dollars 3 billion (Damalas and Koutroubas 2018). An extensive overview of the specific uses of biopesticides can be found in the publication *Integrated Pest Management: Working with Nature* (International Organisation for Biological Control, International Biocontrol Manufacturers Association and Pesticide Action Network 2015).

### Data gaps and limited experience continue to present challenges

There are a number of challenges to both the robust assessment of alternatives and informed substitution. They include gaps in chemical toxicity data, especially for mixtures such as formulated products; in data on potential exposure trade-offs; and in data on the performance of alternatives (Tickner *et al.* 2018). Furthermore, there is a need for more efficient methods and tools to assess economic and technical feasibility, as well as life cycle considerations of substitutes (Jacobs *et al.* 2015; Tickner *et al*. 2018). Toxicity and exposure gaps can be filled to some degree through the development of databases and tools that provide easy-to-access, actionable data and allow users to model missing data. Examples include the OECD's eChemPortal (OECD 2018), the US EPA's Chemistry Dashboard (US EPA 2018) and the Chemical Hazard Data Commons (Data Commons n.d.). Information on tools and potential alternatives can be accessed through databases including the OECD's Substitution and Alternatives Assessment Toolbox (OECD n.d.), the United States Occupational Safety and Health Administration's Transitioning to Safer Chemicals Database (US OSHA n.d.) and the SUBSPORT database (SUBSPORT n.d.).

While it is acknowledged that alternatives assessment and substitution processes imply a certain complexity, it should also be noted that the level of complexity of the assessment and the attributes addressed need to fit the purpose of the assessment (Geiser *et al.* 2015; Tickner *et al.* 2018). Providing flexible guidance and best practices to help manage the complexity and uncertainties in the process will support the engagement of companies, particularly SMEs, in this field. Driven by government policies and market demands, over the past decade researchers and practitioners have developed a variety of methods and tools to assist in evaluating chemical hazards and identifying safer substitutes. Government authorities, academic institutions and NGOs have developed different alternatives assessment frameworks and tools to aid in identifying, evaluating and implementing safer substitutes (Jacobs *et al.* 2015).

## 5.4 Both regulatory and non-regulatory policies are needed

### Policies with provisions for alternatives assessment or substitution

A review of national and international policies identified over 20 policies that include provisions for substitution (Tickner *et al.* 2013). According to available information, however, few such policies exist outside the EU and North America (Table 5.4). Three policy contexts are addressed in Table 5.4: international treaties (including consideration of alternatives evaluation); national or regional regulatory actions (including regulatory provisions specific to alternatives assessment); and non-regulatory initiatives which address substitution.

In Australia, New Zealand, and many countries in Asia and South America the implementation

**Table 5.4** **Examples of treaties, regulatory actions and non-regulatory initiatives with provisions for alternatives assessment or substitution (Tickner *et al.* 2013; SUBSPORT n.d.)**

| Component | What it involves |
|---|---|
| **International treaties** which include consideration of alternatives evaluation | › 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (and amendments)<br>› 1998 Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade<br>› 2001 Stockholm Convention on Persistent Organic Pollutants (and amendments) (includes substitution requirements but no details on alternatives evaluation)<br>› 2013 Minamata Convention on Mercury |
| **Regulatory actions** which include regulatory provisions specific to alternatives assessment | › China: 2002 Law of the People's Republic of China on the Promotion of Clean Production<br>› China: 2006 Management Methods for Controlling Pollution Caused by Electronic Information Products Regulation<br>› European Commission: 2002 Restriction of Hazardous Substances Directive<br>› European Commission: 2004 Carcinogens or Mutagens at Work Directive<br>› European Commission: 2006 Registration, Evaluation, Authorisation and Restriction of Chemicals<br>› European Commission: 2008 Classification, Labelling and Packaging of Substances and Mixtures (CLP Regulation) (requirements for use of safer alternatives in procurement)<br>› European Commission: 2008 Integrated Pollution Prevention Control Directive<br>› European Commission: 2000 End-of-Life Vehicles Directive<br>› EU: Biocidal Products Regulation [(EU)528/2012] (classification-based substitution requirements)<br>› Japan: 1991 Law for Promotion of Effective Utilization of Resources in Japan, and 2008 mandatory industry standard (JIS C 0950, "marking for presence" of specific chemical substances for electrical and electronic equipment)<br>› Norway: Norwegian Environmental Agency's 1976 Norwegian Product Control Act, Section 3A (pollution prevention)<br>› Republic of Korea: 2007 Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles (known as Korea RoHS)<br>› United States: Federal Executive Order 13514, 2009: Federal Leadership in Environmental, Energy, and Economic Performance (single or multiple chemical restrictions with alternatives assessment requirements) |
| **Non-regulatory initiatives** which address substitution | › China: State Recommended Catalogue of Alternatives Materials for Toxic and Hazardous Substances and Products<br>› European Commission: DG Environment's Non-Toxic Environment Initiative – 7th Environmental Action Programme<br>› Sweden: Swedish Chemicals Agency (KEMI) Environmental Quality Objectives, "A Non-Toxic Environment"<br>› United States Environmental Protection Agency (EPA) Safer Choice Program<br>› United States Occupational Safety and Health Administration (OSHA) Transitioning to Safer Chemicals |

of international treaties drives national programmes to use substitution as a chemical management option. Although these policies demonstrate the inclusion of substitution in various chemical management approaches, only a small fraction include specific provisions related to alternatives assessment (Tickner *et al*. 2013). Notable examples include the authorization and restriction requirements under REACH in the EU, and Safer Consumer Products regulation in the State of California (ECHA 2011; California DTSC 2012; ECHA 2014).

Although many firms may substitute in response to regulations, technical or institutional barriers can inhibit the adoption of safer technologies. Experience suggests that a multi-pronged approach consisting of incentives and disincentives is needed to achieve the goals of informed substitution (Tickner and Jacobs 2016). This approach includes requirements for alternatives assessment of chemicals of concern, as well as support structures that facilitate adoption of safer alternatives. Regulation is necessary, but insufficient on its own to drive

**Box 5.4** **The mix of regulatory and non-regulatory policies to support informed substitution (Ashford 2013)**

Regulatory:

- restrictions/limits on chemicals and chemical classes of concern;
- requirements for alternatives assessment with clear guidance and enforcement; and
- information collection requirements on chemical toxicity, uses/functions, and classification.

Supportive:

- training for government and industry on alternatives assessment processes and informed substitution;
- technical support networks and funding for evaluation/testing of alternatives and adoption support;
- databases of alternatives, chemical toxicity;
- demonstration sites, supply chain convening, and case examples of successful implementation; and
- recognition of safer substitutes.

informed substitution and the use of alternatives assessment (Ashford 2013; Tickner *et al.* 2013). Regulations that restrict the use or trade of certain chemicals (or make those chemicals unacceptable in the marketplace) can lead to chemical de-selection (eliminating the chemical from a product or process without consideration of alternatives). The right mix of regulatory and non-regulatory (supportive) policies is essential to support innovation and substitution (Box 5.4).

Evaluations of past efforts suggest that institutional capacity within firms, to more effectively evaluate and adopt safer alternatives to hazardous chemicals, can be enhanced through incentives-based government initiatives that include research and evaluation support, guidance, information on alternatives, demonstration projects, technical assistance, databases, training, and assistance for supply chain networking of firms (Ashford 2013; Tickner

© Office of Technical Assistance and Technology, Kevin Souza with obsolete carbon adsorbers

**Box 5.5** **The importance of policies that include technical support structures: chlorinated solvent substitution (Jacobs *et al.* 2014; US NRC 2014; Office of Technical Assistance and Technology 2015; TURI 2017)**

Trichlorethylene (TCE) is a commonly used chlorinated solvent that is carcinogenic to humans (Group 1) according to the IARC and one of the most common contaminants found in hazardous waste sites in the United States. In the State of Massachusetts, under the Toxics Use Reduction Act, companies using listed toxic substances are required to annually quantify the use and emissions/waste of these chemicals and conduct an assessment of alternatives to reduce the use of the chemical every two years. With technical and research support from the Massachusetts Toxics Use Reduction Institute (TURI), funded by a small fee on chemicals, manufacturers using TCE in degreasing metal parts and other applications were able to evaluate and implement safer, water-based alternatives, reducing use of this chemical by some 95 per cent in the state and saving companies money. The TCE case in Massachusetts demonstrates the critical importance of research and technical support in overcoming technical barriers to substitution. To avoid potentially problematic solvent substitutes, a functional substitution approach to solvents as a class would be helpful.

and Jacobs 2016). For example, experience in the United States shows that toxics use reduction policies which promote substitution are more effective when supplemented with technical support structures to facilitate adoption (Box 5.5). Allowing companies degrees of flexibility in how they evaluate and adopt alternatives may lead to better outcomes and therefore more substitution. If incentive-based approaches are not successful in achieving stakeholder buy-in and cooperation, regulatory frameworks can be explored and implemented.

### The roles of governments and industry

Policies can help clarify the appropriate roles of government, industry and other stakeholders in alternatives assessment and substitution processes. In developing and implementing actions, balancing the appropriate roles of government, industry and other stakeholders (given their various resources, skills and strengths) is essential. Providing certainty regarding existing and potential future regulatory requirements for chemicals is a critical element in the decision-making process of companies.

Similarly to risk assessment, alternatives assessment and substitution can be time- and resource- intensive and context/application-dependent. Unlike risk assessment, which relies primarily on hazard and exposure data, alternatives assessment requires information on functional and application requirements, manufacturing and use conditions, performance and cost. Informed substitution is focused on the practical adoption of solutions. Experience indicates that companies and those using chemicals subject to alternatives assessment are often better situated to evaluate alternatives for their particular application in ways that can most effectively lead to the implementation of safer substitutes in their processes and products (EC 2017). Companies and users of chemicals are responsible for understanding the chemicals they are using (function/uses, toxicity, potential exposures); establishing processes to systematically and thoughtfully evaluate and adopt alternatives, involving workers, communities and supply chain stakeholders as necessary; evaluating implementation for potential trade-offs and improvement opportunities; and transparently presenting results and decisions. Companies may have to reach out to their supply chains to better understand ingredients in an article or formulation and use conditions.

Governments have an important role to play in establishing the mandates for alternatives assessment and substitution; developing criteria for chemicals and materials to avoid in substitution processes (e.g. less-safe and safer chemicals); establishing clear guidance and requirements for the alternatives assessment process; and developing metrics and the means of enforcement to monitor the substitution process. Governments can also establish non-regulatory mechanisms that help achieve programme goals and accountability by: providing actionable data on hazard and exposure trade-offs to inform alternatives assessment; providing guidance, technical and research support and incentives for substitution; providing clear, consistent signals to the marketplace so that early actions can take place; and convening societal stakeholders. When a chemical is identified as being of concern, both industry and government are responsible for ensuring that adequate processes are in place to support the transition to safer alternatives. They may need to convene representatives across sometimes very deep and complicated supply chains and users.

There may be instances where government-conducted alternatives assessments can support industry actions (e.g. in the case of priority chemicals or sectors where there is societal demand for policy changes, or existing debate around the availability of alternatives for a particular substance). For example, the US EPA's Design for the Environment programmes (US EPA 2017) have undertaken alternatives assessments for several high-profile chemicals and applications, such as various flame retardants. The assessments required significant time, resources and stakeholder engagement. This experience suggests that while only a small number of such government-led assessments could be undertaken, they might have a large impact in driving the transition to safer alternatives by providing baseline analysis to inform industry decision-making. Greater certainty with respect to existing and potential future regulatory requirements on chemicals is a critical element in the decision-making process of companies.

Given the variety of approaches that countries and businesses have used to implement alternatives assessment, a growing amount of expertise and experience is being generated from past and present alternatives assessments and substitution cases. Governments can play an important role in establishing systematic efforts to collect and compile relevant case examples and lessons learned that can serve as a critical source of knowledge to identify and address common challenges; identify and share good practices and success stories; and make the business case for substitution. An example is a recent report developed by the Regional Activity Centre for Sustainable Consumption and Production (Weber *et al.* 2018), which provides a number of case studies illustrating the replacement of toxic chemicals with safe and innovative alternatives. In a Canadian "combined government discussion paper and science committee report on informed substitution" a review is provided of opportunities to support informed substitution, comparative chemical hazard evaluation tools which are available, and the use that can be made of existing data (Government of Canada 2018).

### Stakeholder engagement and harmonized methodologies are needed

Stakeholder engagement and collaboration are critical to address gaps in alternatives assessment methods and support the ultimate adoption of safer alternatives. For example, workers often have important information on a production process or potential exposures. They are also the ones who will be implementing an alternative (which may include changes in work processes). Adoption will be more effective if those using an alternative are involved. Actors along the supply chain, from chemical suppliers to product manufacturers to retailers, can share important information on customer needs, options that might be available and how an alternative might impact product quality, as well as information that would help to understand potential trade-offs. Stakeholder engagement helps ensure critical questions are asked during the assessment process to ensure the assessment is sufficiently complete and that implementation of substitutes occurs in an efficient manner, guaranteeing greater adoption.

During the assessment process, capacity building and greater coordination among stakeholders would help build the consistent application of alternatives assessment globally and to maintain some degree of flexibility in the methods used to support different substitution contexts. Capacity building programmes, such as the UNIDO and UNEP National Cleaner Production Centres and Networks, which can enhance working knowledge

**Box 5.6** **Substitution of methyl bromide: the importance of having a range of alternatives and stakeholder engagement (UNEP 2014)**

Under the Montreal Protocol there has been a global phase-out of the use of controlled methyl bromide (MeBr), a powerful ozone depleter and human health toxicant linked to prostate and other cancers. For decades methyl bromide was the preferred soil fumigant for controlling a range of pests and pathogens in soil, among other uses. The search for suitable alternatives revealed that no single alternative was effective for all uses. Identification of alternatives needed to be addressed on a case-by-case basis, depending on the specific needs of the end user, regional or climactic differences, and economic feasibility. In many cases a combination of different alternatives, including chemical pesticides and non-chemical options such as steam sterilization and IPM techniques, was identified as the best approach for substitution.

There is a need for support and enforcement structures to accompany substitution programmes. Many alternatives to the use of methyl bromide, such as IPM, are knowledge-intensive. They require a broad understanding of alternative agricultural practices, as well as access to information on technological developments and improved farming techniques. Engagement and training of stakeholders, provision of technical assistance, and adaption of alternative technologies to local conditions are therefore crucial to successful substitution.

of alternatives assessment and substitution, are available to all interested parties (UNIDO 2018). Stakeholder engagement is equally important in some contexts in understanding the availability and functionality of the range of alternatives which can be used, depending on the specific circumstances (Box 5.6).

### Transitioning to safer chemicals in countries with limited resources requires action on several fronts

Developing countries and countries with economies in transition are confronted by several barriers with respect to supporting the informed substitution of chemicals. Even when regulatory efforts such as the implementation of international treaties are in place to guide


© HCWH Asia/Faye Ferrer, Nurses from Various Hospitals in the Philippines supporting the Launch of the "Mercury-Free Health Care 2010" Campaign substitution efforts, there are often limited resources to collect and properly dispose of the toxic materials that were replaced. Technical resources to evaluate chemical hazards, or to identify alternatives and enforce substitution requirements under international treaties, are also limited. To remove these barriers, there is a need for technical support, capacity building and case examples of successful substitutions (UNEP and WHO 2014) (Box 5.7). This does not mean that informed substitution cannot and does not happen in developing countries. However, it often requires collaboration between research institutions, governments and employers to address gaps in capacity and information. Thus, evaluating both successful and unsuccessful substitutions, and factors that lead to success or failure, and making the results publicly available are critical to ensure effective informed substitution and improve capacity in developing countries and those with economies in transition (Intergovernmental Forum on Chemical Safety 2008).

The private sector has a critical role to play in building capacity for informed substitution in developing countries and countries with economies in transition. This includes requirements by multinational companies that are engaged in manufacturing (or that contract manufacturing), which their suppliers implement sustainable substitution policies. These companies also need to provide technical support to regional companies and government agencies so they can undertake similar activities. Start-up companies can also play an important role in developing safer substitutes in developing countries, as many of them are associated with university research resources. Strong chemicals management foundations in developing countries remain a priority and can contribute to the success of substitution programmes.

**Box 5.7** **Mercury-free hospitals: the importance of participatory substitution programmes and alternative technology replacements (Burgos-Hernandez 2009; WHO 2015; Health Care Without Harm 2018)**

Mercury is a persistent, bioaccumulative and toxic chemical. Its global phase-out is covered under the 2013 Minamata Convention. The Minamata Convention bans new mercury mining and calls for increased controls on mercury emissions and phasing out of mercury use in many products and processes. Hospital use of mercury-containing products is significant. The World Medical Association has urged regional and national medical associations to work within their institutions to reduce their mercury use.

In 2009 a joint project led by the University of Massachusetts Lowell, in the United States, implemented mercury replacement programmes in hospitals in Mexico and Ecuador. This programme used a participatory format that vertically engaged and trained all stakeholders on the dangers of mercury. Working groups in each hospital identified mercury thermometers, which are made of glass and easily break, and mercury sphygmomanometers (blood pressure cuffs which must be filled manually with liquid mercury) as significant sources of exposure and ideal candidates for replacement. Mercury thermometers were replaced with digital fever thermometers, and mercury sphygmomanometers were replaced with aneroid sphygmomanometers which use pressurized air.

These replacements illustrate the importance of technology substitutions, where equipment that uses a toxic chemical is replaced with a non-chemical option. Relying on hospital staff to identify problem areas and implement solutions resulted in greater ownership of preventative practices, strengthened networks, and provided a structure for continued training efforts.

## 5.5 Potential measures to advance assessment of chemical and non-chemical alternatives

To avoid regrettable substitutions, it is important to further refine and harmonize alternatives assessment methods, based on functional substitution as well as on the exchange of lessons learned in developing and deploying alternatives. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance assessment of chemical and non-chemical alternatives:

- Focusing on functional substitution, further develop and harmonize efficient methods and tools for the comparative assessment of options to replace a chemical of concern, including their economic and technical feasibility.
- Scale up the use of (and refine) both regulatory and non-regulatory supportive instruments, including clear criteria and guidance for alternatives assessments.
- Identify case studies on (and ensure wide availability of information about) successful and unsuccessful substitutions, as well as on factors that lead to success or failure.
- Strengthen the applicability to alternatives assessment of existing databases of information on chemical functions, hazards, potential exposures and life cycle impacts.

# 6/ Chemical risk management in facilities and during production

## Chapter Highlights

International efforts are under way to facilitate a paradigm shift from managing disasters to preventing them – and to better integrate chemical accidents into broader emergency planning.

Guidance on preventing, preparing for and responding to chemical accidents is available from various bodies.

Stakeholders are often not sufficiently engaged and/or informed.

To avoid future accidents, awareness-raising, sharing of lessons learned from regulatory oversight, and promotion of good practices are essential.

While SMEs face particular challenges in managing risk, they often lack knowledge and capacity. There is a need for increased oversight and collaboration in this regard.

Workers in the informal sector are particularly at risk.

Previous chapters largely focused on risk assessment and risk management decision-making, along with opportunities to accelerate these processes. This chapter provides further insights into risk management challenges during chemical production, particularly with respect to the risk of chemical accidents. It also addresses risk management in SMEs and in the informal sector. This type of risk management presents specific challenges in many developing countries.

## 6.1 Understanding and addressing the risks of chemical accidents

A chemical accident can be defined as the unintentional release of one or more hazardous substances that could harm human health or the environment. Chemical accidents may occur at fixed locations (e.g. factories or warehouses) or as a result of transport, the use of pipelines and exploration activities (e.g. operation of offshore oil platforms). The continuing occurrence of chemical accidents and their negative impacts on human health and the environment (as discussed in Part I Ch. 5, 7) point to the need for stakeholders around the world, particularly industry, to scale up actions to prevent, prepare for and respond to chemical accidents. To support these actions, policy frameworks and support programmes have been put in place internationally. The Sendai Framework for Disaster Risk Reduction 2015-2030, recently adopted by UN Member States, provides an overarching context and seeks to foster a paradigm shift – from managing disasters to preventing them – through a greater focus on managing disaster risk in an integrated way. Addressing risks from chemical accidents is an important dimension of the Sendai Framework (United Nations Research Institute for Social Development [UNRISD] 2015).

**Table 6.1** Selected activities of organizations engaged in addressing chemical accidents (Inter-Agency Coordination Group for Industrial and Chemical Accidents 2017, p. 7.)

| Organization | Prevention | Preparedness | Response | Post-accident | Learning |
|---|---|---|---|---|---|
| **OECD** | Guiding Principles for Chemical Accidents, Prevention, Preparedness and Response | | | | Major Accident Reporting System (eMARS) |
| **UNECE** | Transboundary Effects of Industrial Accidents Convention | | | | |
| **EU** | Seveso III Directive, Civil Protection Mechanism | | | Environment Liability Directive | eMARS |
| **JEU** | | UN Disaster Assessment and Coordination Mechanism, Flash Environmental Assessment Tool | | | |
| **UN Environment** | Flexible Framework, Awareness and Preparedness for Emergencies at Local Level (APELL), Responsible Production toolkit | | | | |
| **UNISDR** | Sendai Framework for Disaster Risk Reduction 2015-2030 | | | | |
| **WHO** | | International Health Regulations | | | Event Management System (EMS) |
| | Public health management of chemical incidents | | | | |
| **EPSC** | Member network | | | | Member network |

Policy, no intervention    Intervention based    Regulation/legislation/convention

EPSC: European Political Strategy Centre; JEU: Joint UN Environment/UN Office for the Consideration of Humanitarian Affairs Environment Unit; UNISDR: UN Office for Disaster Relief Reduction.

Several specialized international programmes provide targeted analysis and guidance to address various aspects of addressing chemical accidents. For example, in the UNEP Flexible Framework for Addressing Chemical Accident Prevention and Preparedness governments are encouraged to develop, improve or review Chemical Accident Prevention and Preparedness (CAPP) programmes at the national level, which would include reviewing laws, regulations, policies, guidance and other instruments (UNEP 2010). Other important international initiatives include the OECD Chemical Accidents Programme; the UNECE Convention on the Transboundary Effects of Industrial Accidents (TEIA); the WHO International Health Regulations and related activities concerning the public health management of chemical incidents and emergencies; and the Organisation for the Prohibition of Chemical Weapons chemical safety and security programmes. An overview of selected programmes and guidance of international relevance was recently compiled through an activity involving several agencies (Table 6.1) (Inter-Agency Coordination Group for Industrial and Chemical Accidents 2017).

## The importance of identifying chemical hazards

Effective management of chemical accident risks requires knowledge about the presence and location of chemical hazards. Any operator whose activities involve the production, handling or storage of dangerous substances should identify the specific accident risks associated with the types of substances used and handled, the volumes present, and the processes in which they are used. This knowledge should be incorporated in practices that prevent exposure to dangerous substances and help to ensure preparedness should such exposure occur.

Government efforts to reduce chemical accident risks generally require the establishment of a chemical hazard inventory in which industrial activities associated with the use of dangerous substances (including sites, pipelines and transport routes) are identified, stored in a database and located, ideally on a map. Some countries develop hazard rating systems that allow prioritization of different activities by level of hazard on the basis of other information, including volumes and types of dangerous substances; types of activities; distance from populated areas; compliance records; and past accident information. Several national hazard rating schemes are described in the European Commission Joint Research Centre (EC JRC) and UNECE publication on hazard rating systems in EU Member States, European Economic Area (EEA) countries and national competent authorities under the UNECE Convention on TEIA (EC JRC and UNECE 2016).

Existing CAPP legislation (e.g. the EU Seveso Directive and the United States Risk Management Plan Rule) provide useful models for the identification of hazardous operations (EC 2017; US EPA 2018). This legislation includes lists and categories of dangerous substances and the threshold quantities that indicate a certain level of hazard. UNEP's Flexible Framework and the OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response (OECD 2003) also provide implementation guidance to support countries as they begin to identify the kinds of dangerous substances present, as well as companies that might be using these substances.

### Enhanced sharing of knowledge and lessons learned

Sharing lessons learned begins with establishing mechanisms for accident reporting. Each company engaged in hazardous activities should maintain a register of accidents and near misses, as well as a programme for systematic analysis and implementation of recommendations resulting from an accident. Lessons learned from the most serious accidents and near misses should be made available to other operators engaged in hazardous activities. Data are still not available on chemical accidents in many parts of the world: companies may not be investigating them, or results from accident investigations may not be shared. Furthermore, there may be no government or industry mechanism encouraging them to do so.

In some regions and industries, however, public databases that contain chemical accident information have been established. These include, notably, the EU eMARS database and various country and industry databases (e.g. ARIA, ZEMA, CSC, RIHAD) as well as the published results of investigations and studies concerning chemical accidents. eMARS is a public database containing over 900 reports of chemical accidents and near misses reported by EU, EEA, OECD and UNECE countries. Reporting major accidents to eMARS is compulsory for EU Member States when the event meets the criteria defined in Annex VI of the Seveso Directive. In the case of non-EU OECD and UNECE countries, reporting accidents to the eMARS database is voluntary but is regularly carried out (Inter-Agency Coordination Group for Industrial and Chemical Accidents 2017). Accident databases only provide information on chemical accidents that have already happened.

The probability that serious chemical accidents will occur in highly industrialized countries is generally low. In these countries only some risks are manifested as accidents during a given time period, while in other countries accidents take place more frequently (see Part I, Ch. 5). Additional research on the national and regional dimensions of chemical accidents has been carried out, including in China (He *et al.* 2011; UNEP 2011), India (Sengupta *et al.* 2015) and Africa (UNEP 2017). It suggests that when facilities that process hazardous materials are transferred from developed to developing countries, the process safety standards for such facilities which applied in the former should not be lowered, irrespective of local regulations.

Exchange networks of practitioners can be valuable sources of information on chemical accident risks, particularly for identifying ways to prevent accidents. Depending on the topic, these networks can consist of groups of experts in the same industry or the same profession; government regulators; and cross sections of experts from government, industry and academia. Such information exchange helps operators engaged in hazardous activities assess risks in order to improve their risk management strategies, while it also helps authorities prioritize hazard sources and topics for inspections. Along with information from accidents, expert exchange can substantiate the need for modifications to technical standards, improvements to regulations, and enforcement policy regarding safety performance at installations. There are many examples of such groups in developed countries and in multinational industries, including the Center for Chemical Process Safety (CCPS), the Energy Institute, the International Association of Oil and Gas Producers, the EU Seveso Expert Group, and the OECD Working Group on Chemical Accidents. There are also many examples of exchange networks that guide the establishment of new networks in regions and industries where they are needed.

### Understanding the causes of chemical accidents

Past accidents cannot directly provide information on accidents that might happen. Hence other types of information are needed in order to identify activities and practices that are likely sources of future accidents, so that measures can be taken to reduce risks before accidents occur. The information in chemical accident databases, together with the publication of the results of investigations and studies concerning these accidents, have facilitated a proliferation of studies whose purpose is to identify their causes.

Analysis of past accidents is valuable for developing insights into why accidents occur in the chemical processing industry, together with the damage they cause. Such analysis of major chemical accidents, and the determination of required measures and communication of results, should be carried out by independent authorities. This can provide "wisdom of hindsight" to help prevent accidents or mitigate the impacts of those which nevertheless still occur (Tauseef, Abbasi and Abbasi 2011). To avoid future accidents, it is essential to share good practices and implement the recommendations in these analyses. There are ongoing efforts to improve analytical methods and to identify more effective approaches to the prevention of accidents and their consequences.

It has been shown that accidents occurring today frequently result from well-known and well-understood failures which had already been identified in the case of past accidents. Abu Bakar *et al.* (2017) reviewed 770 major accidents using four summary categories associated with the risk-based process safety (RBPS) framework. They concluded that the most common accident contributors were linked to process hazards (19 per cent), operating procedures (17 per cent) and lack of employee participation in process safety management (12 per cent). Gyenes and Wood (2014) used the seven elements of a safety management system from the 2012 EU Seveso Directive to review the causes of 86 major accidents notified to the eMARS database. They concluded that the major cause of accidents was

© Claudia Cabal, an electrical station storing PCB equipment in Paraguay following a large fire related to deficiencies in operational control (28 per cent). Other studies have examined, for example, the roles of maintenance (Okoh and Haugen 2014) and of equipment failure (Kidam and Hurme 2013).

The study of accidents can also reveal new sources of risks associated with changing technologies and with business practices. Taylor *et al.* (2017) looked at findings from 12 industrial catastrophes, including four chemical events. They found that increasing engineered complexity, technical specialization, fragmented contractual arrangements and other factors make it increasingly difficult for individuals and organizations to recognize weaknesses in risk control. Often problems arise because current approaches to risk analysis are not able to consider adequately the influence of a vast array of relevant inputs such as leadership issues, operational attitudes and behaviours, commercial and budgetary pressures, and communication issues.

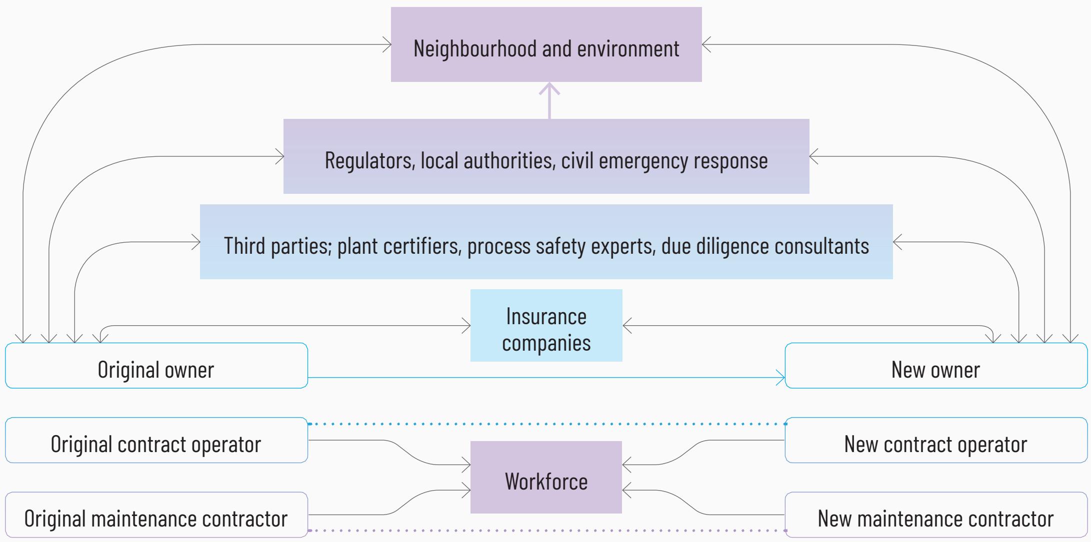
In addition, accident analysis can identify complex causality and systemic vulnerabilities resulting from the way an organization operates. As Sklet (2004) observed, experience with accidents has shown that major accidents almost never have a single cause; most accidents involve multiple, inter-related causal factors. This complexity should be reflected in the accident investigation process. Various analytical techniques are available to support investigators in structuring information and focusing on the most important features.

### Emerging topics of interest

Lessons emerging from recent accidents cover a spectrum of actions to ensure improved chemical accident prevention, preparedness and response. These actions range from strong engagement by senior leaders (in public authorities and companies) (OECD 2012) to addressing emerging risks associated with growing production and use of clean fuels, cybersecurity, and technological accidents caused by natural disasters.

One issue being discussed by the international community concerns possible risks that result when ownership changes. At hazardous facilities such changes of ownership are very common and can potentially affect key aspects of safety management (OECD 2018a) (Figure 6.1). Current and new owners may be specialist companies with a significant industry background, or they may be "non-specialist" companies with a more

**Figure 6.1** Stakeholders in the change of ownership of hazardous facilities (adapted from OECD 2018a, p. 14)



diverse business portfolio. In certain cases, poorly managed change of ownership (including oversight responsibilities) could potentially have detrimental consequences for safety at a facility.

The death of many private and public firefighters during chemical accidents is another cause of concern. Efforts to develop emergency planning – with strong specialized training for first responders and direct cooperation with companies – should continue (OECD 2018b). Other topics emerging from recent accidents include the safety of underground gas storage; the safety of pipes and (long distance) pipelines; risks of chemical accidents in harbours; risks posed by facilities where highly active substances are handled (including high potency active pharmaceutical Ingredients and agrochemicals); the management of ageing facilities; improving clean-up and recovery and, more generally, ensuring proper safety maintenance programmes; and addressing risks arising from natural hazard triggered technological (Natech) accidents.

### Natural hazard triggered technological (Natech) accidents

Natural hazards can trigger fires, explosions and toxic releases at hazardous installations and in critical infrastructure (e.g. at fixed chemical installations, in oil and gas pipelines and on offshore platforms). "Natech accidents" frequently occur in the wake of natural disasters. They often have severe long-term consequences for the population, the environment and the economy. The risk of Natech accidents is expected to grow as a result of climate change and increasing industrialization. In particular, climate change is likely to increase the frequency and severity of hydro-meteorological hazards, raising concerns about an increase in the number of Natech accidents due to storms. Preliminary studies indicate the extent of the damage severe storms can cause (Krausmann and Salzano 2017). There are currently no systematic analyses of storm-triggered Natech accidents. Nevertheless, lessons can be learned from the impact of extreme weather and climate events such as Hurricane Harvey, which caused extreme precipitation (particularly over Houston, Texas in the United States and the surrounding area) in August 2017, resulting in extensive flooding, loss of life, high economic costs, and impacts on critical infrastructure, airports and industry (Sebastian *et al.* 2017; van Oldenborgh *et al.* 2017; Jonkman *et al.* 2018; Gori *et al.* 2018) (Box 6.1).

To address Natech accidents and manage their consequences when they do occur, targeted prevention, preparedness and response are needed (Krausmann and Salzano 2017). However, disaster risk reduction frameworks do not always consider technological hazards, while chemical accident prevention and preparedness programmes often overlook specific aspects of Natech risks. Natech risk assessment tools and guidance for industry and government authorities are therefore needed to support better Natech risk management at the national and local levels (UNISDR 2018). In addition, Natech risk assessment is an important instrument for determining where Natech risk spots exist within a region and where detailed risk assessment is required. Although the potential consequences of such accidents are understood, the cost of additional safety measures to reduce Natech risk can result in reluctance to accept that these risks exist and to act to reduce them (Girgin, Necci and Krausmann 2017). Guidance for prevention, preparedness and response to address natural hazards triggering technological accidents is available from the OECD (OECD 2015).

### Commitment by senior company leaders, effective governance, and capacity development

Systematic data on the economic cost of chemical accidents are lacking, and it is often difficult to prove to senior officials that the resources spent on accident prevention pay off (OECD 2018c). If no accidents occur, less attention may continue to be paid to prevention. Yet the costs of chemical accidents, which may be significant, can affect the stock value of an affected company (Makino 2016). Efforts are ongoing to substantiate the risks and costs of chemical accidents and raise awareness about accident prevention at higher policy levels (OECD 2018c). The engagement of senior leaders of companies in understanding the risks posed by their facilities, and the importance

**Box 6.1** **Lessons learned from Natech accidents triggered by Hurricane Harvey (Necci, Krausmann and Girgin 2018)**

Hurricane Harvey made landfall on the Gulf coast of Texas in August 2017. The lessons to be learned from the Natech accidents triggered by this storm include:

- Preparation for past levels of storm severity is not sufficient. In view of ongoing climate change, storm frequencies and intensities could change and, with them, the associated Natech risk.
- Although natural hazards and vulnerabilities may be known, industry does not always adequately protect its equipment from impacts. In areas where there is a known flood hazard, use of protection measures should be enforced to prevent equipment damage and the subsequent release of hazardous materials.
- Floodwaters are a transport vector for released toxic or flammable substances, distributing them over potentially wide areas. Where there is an ignition source, devastating fires can occur which are also transported with the flood. This risk is as yet inadequately considered.
- Current and former waste sites are vulnerable to flooding, but little has been done to mitigate the risks they pose. Such sites should be protected from flooding, and investment should be allocated to completing remediation activities as quickly as possible.
- Significant airborne emissions can be created by flaring during facility shutdown and restart operations before and after a storm. Areas with a high density of industrial facilities should have plans to schedule restart operations in a way that does not affect air quality.

of investing in process safety, is critical in this process.

Integrating chemical accidents in emergency planning at several levels of governance helps ensure that the risks and management of chemical accidents are addressed at the community, municipal, regional and national levels in an integrated way (UNRISD 2018). Effective land use planning policy is an essential part of this integrated approach, as is the engagement of the health sector in prevention, preparedness, response and recovery (WHO 2018). Coordination across borders may be relevant in order to address the risk of transboundary accidents.

The activities described above require the development of effective risk management systems and the scaling up of capacity development efforts. At the national level, Cambodia, Mali, the Philippines, Senegal, Sri Lanka and Tanzania have prepared national roadmaps to develop CAPP programmes with support from the United Nations Environment Programme and the SAICM Quick Start Programme Trust Fund. Common priorities identified through these projects include adequate enforcement of existing regulations; drafting new legal texts to implement CAPP; establishing ongoing coordination mechanisms; and establishing a central information management system (i.e. a database) (UNEP 2015). Given the role played by human factors in causing chemical accidents, training concerned individuals is a key aspect of capacity development for chemical accident prevention, preparedness and response. To better measure these and other capacity development efforts, a capacity development framework has been proposed to assess progress and help compare capacity levels for prevention of and preparation for chemical accidents in countries (Baranzini *et al*. 2018).

## 6.2 Chemical risks in developing country SMEs

### 6.2.1 Challenges in developing country SMEs

#### Use of safety data sheets

Many SMEs in developing countries routinely use and handle chemicals. When they do so, attention needs to be paid to accompanying labels and safety data sheets (SDS). Often, however, developing country SMEs carry out their activities without having proper on-site list of hazardous substances, accompanied by corresponding SDS. Moreover, employees receive only limited training and re-training to help them understand and apply the information found on labels and SDS (Massey 2008). To be effective, communication of risks to employees needs to be simple and practical, taking into account the context and their level of education. A study in China that assessed a behaviour-based safety management approach showed that workers identified safe and unsafe practices and took part in addressing them (Yuan and Wang 2012).

In developing country SMEs a number of quality insufficiencies in the SDS system can be observed. These include the SDS frequently being incomplete or inaccurate; lacking important information about guidelines for controlling exposure; and having been created by the manufacturer and therefore possibly not having been subject to significant scrutiny by government authorities. SDS may also be inconsistent; for example, in some cases several firms sell the same chemical but the corresponding SDS are different (Massey 2008).

There are several possible reasons for the underuse or inadequacy of SDS in the SME sector. For example, those prepared by chemical manufacturers to comply with regulations may not meet the needs of the people exposed to the chemicals; an example would be SDS in a language that workers and others who are supposed to read them cannot understand. On the other hand, SMEs that use chemicals, but have a poor understanding of the SDS, are unlikely to have much interest in trying to benefit from them.

### Process safety

The Risk Based Process Safety (RBPS) approach recognizes that all hazards and risks in an operation or at a facility are not equal. Consequently, safety-related resources are attributed in a way that focuses on estimated greater hazards and higher risks. According to the Center for Chemical Process Safety (CCPS) (2017), "using the same high-intensity practices to manage every hazard is an inefficient use of limited resources. A risk-based approach reduces the potential for attributing an undue amount of resources to managing lower-risk activities, thereby freeing up resources to address higher-risk activities."

Commitment to process safety addresses a number of key elements, including the importance of a process safety culture; strict compliance

with standards; promotion of process safety competencies; total workforce involvement; and a strong stakeholder outreach programme. Process knowledge management, coupled with hazard identification and risk analysis capability, are key elements for understanding process safety. Without risk-based process safety prioritization, it would be difficult and unaffordable for most developing country SMEs to fully address hazards and risks (Verbano, Venturini and Venturini 2013; CCPS 2017). Developing country SMEs also need more technical assistance with the design and implementation of process safety management systems.

#### Occupational health and safety

Many work environments in developing country SMEs are dangerous. Not only do a large share of occupational accidents in these countries occur in SMEs (Nyirendaavwil, Chinniah and Agard 2015), but chemical accidents in SMEs are seriously under-reported because of poor data and analysis capabilities. Risks therefore need to be systematically assessed, analyzed and, where necessary, reduced to improve safety at work (Nordlöf *et al.* 2017).

The adoption of a functional occupational health and safety management system (OHSMS) by an SME is an important measure that can lead to fewer occupational accidents. Regularly measuring and keeping track of a company's safety culture, and openly discussing occupational health and safety (OHS) values, are priorities in this context. Factors such as the company's size, its safety culture, the extent of high-level company commitment, lack of relevant skills, lack of technical know-how, lack of formalized routines, and financial affordability need to be understood and addressed (Nordlöf *et al.* 2017). In Malaysia, for example, although OHS regulations exist, 80 per cent of facilities investigated failed to fully comply with them (Hong, Surienty and Kee 2011). Where OHS takes a back seat to productivity, competitiveness and profitability, (complete) adoption of an OHSMS is prevented in developing country SMEs.

#### Access to finance for occupational health and safety management systems

The level of financial performance can be associated with occupational health and safety management (OHSM) practices, as demonstrated in a Swedish study on companies' credit worthiness. According to this study, better financial performance and better OHSM practices can reinforce one another in a positive and cyclical spiral (Nordlöf *et al*. 2017). In some countries the government provides important financial and technical assistance to support OHS implementation in SMEs. Such is the case with support provided in Malaysia by SMECorp, an agency under the Ministry of International Trade and Industry in charge of overall policies and strategies for SMEs (Hong, Surienty and Kee 2011). Similar specialized agencies are found in other countries. Sometimes National Cleaner Production Centres assume this role. An interesting approach in some countries includes partial subsidization of occupational health and safety activities. For example, in Japan and Finland half the cost is subsidized (Mizoue *et al.* 1999).

### 6.2.2 Improving chemical safety in developing country SMEs

#### Further steps in the transfer of safety technology

The incidence of occupational injuries and diseases associated with industrialization has declined markedly in highly industrialized countries as a result of the adoption of engineering controls, strict use of protective equipment, reliance on safer machinery and processes, and greater adherence to applicable regulations and labour inspections (Kim, Park and Park 2016). To improve OHS in all countries, modern legislation and consequent interventions to help improve work environments increasingly need to take account of the specific characteristics and needs of SMEs (Legg *et al.* 2015). In this respect, it is also important for advanced safety technology to be used in developing country SMEs.

Developing country SMEs need assistance in making technological changes. Facilitating transfers of safer technologies to these SMEs would be of great importance in preventing accidents at the workplace. A crucial first step would be for these SMEs, if feasible, to replace dangerous old equipment (Yuan and Wang 2012). Besides improving OHS conditions, technology transfers could promote the sustainable development concepts of recovery, reuse and recycling. Universities and research centres can be an important source of knowledge and experience to share with SMEs in order to support their transition to better and safer technologies and practices. Bhandubanyong and Pearce (2017) identified the need for foundries in Thailand, especially in the SME sector, to receive more encouragement, guidance and support in seeking to make technical improvements in their operations, for example through better cooperation and interaction with university/government R&D centres such as the National Metals and Materials Technology Center. Similar opportunities exist in other developing countries with respect to many types of SMEs and activities.

### Promoting a more proactive safety culture in SMEs

A key element of occupational safety and health management is the promotion of a culture of prevention within an enterprise (ILO 2014). Lessons from past disasters underline that it is of the highest importance to create a corporate culture in which safety is fully understood and treated as the number one priority in any business. It is clear that an occupational safety and health management system is not effective unless there is a positive safety culture in the workplace (Kim, Park and Park 2016). The characteristics of a positive safety culture include proper leadership that is highly visible and committed to safety, as well as clear communication of safety as a priority value that cannot be traded off against cost and schedule (International Atomic Energy Agency 2006; Unnikrishnan *et al.* 2015). In a developing country setting it is important to remember that many SMEs start as family businesses. In such cases, management may fail to fully understand concerns about chemical risks and occupational safety. Initiating a safety culture will therefore need to start with the engagement of management and various behavioural aspects will need to be taken into account (Yuan and Wang 2012).

Guidance provided in the ILO Convention concerning the Promotional Framework for Occupational Safety and Health (ILO 2009) calls for an occupational safety and health management system approach. The main purpose of such a system is to pursue continual improvement in occupational safety and health performance through the use of the Plan-Do-Check-Act cycle. The Convention sets out how national policy, national systems and national programmes should be designed in order to promote continuous improvements in occupational safety and health (Kim, Park and Park 2016).

Linkages and the interaction of companies with other players in the field (e.g. through value chain linkages with global markets or through being part of a multinational company) are encouraging the introduction of voluntary standards, global environmental management and corporate social responsibility systems; sustainability reporting initiatives; and advanced product quality programmes – all of which contribute to improved environmental performance at chemical production facilities, including SMEs (He and Yang 2012).

### Promotion of investments in chemical industry parks

Clustering companies creates synergies and economic benefits by providing shared access to networks, suppliers, distributors, markets, resources and support systems (Heikkilä *et al.* 2010; Reniers and Amyotte 2012). Since 2006 China has adopted a policy of relocating SMEs to chemical industry parks, rather than leaving them dispersed throughout the country. Clustering is considered to facilitate the safety and environmental supervision activities of chemical companies by park management authorities and relevant government agencies (Zhao *et al.* 2013). It is clear that collaboration between adjacent plants to prevent (internal and external) domino effects in a chemical industrial cluster can help save lives and avoid considerable costs that might arise as a result of chemical accidents (Reniers, Cuypers and Pavlova 2012)

Clustering can facilitate/incentivize materials exchange. For example, waste from one facility may be input for another. Simple practices such as materials exchange can prevent significant volumes of hazardous waste or effluents reaching waterways or soils (Massey 2005). However, realizing the OHS benefits of what are sometimes referred to as "eco-industrial parks" is proving difficult in developing countries and could be strengthened (Kultida *et al*. 2015).

Clustering companies characterized by substantial use of chemicals in a special area that provides the right infrastructure is desirable. For example, the Government of Bangladesh has decided to implement this approach with tannery SMEs in Dhaka City. Tanneries had been functioning in an unplanned manner, scattered and surrounded by populated areas and with no effluent treatment. The government therefore proposed a new location, with land dedicated to industrial plots and to a central effluent treatment plant, disposal yard, electricity sub-station and other necessary infrastructure. All tannery operations are being moved to this area. Similar initiatives could be implemented with respect to other traditional and significant activities in developing countries, such as brick production and foundries (Paul *et al*. 2013).

### 6.2.3 Further research on (and knowledge about) chemical safety in SMEs is needed

Most occupational health and safety research, policy and legislation have been – and still are – skewed in favour of large enterprises (defined as those with more than 250 employees) that have the resources to influence, interact with and contribute to policy development and research (Legg *et al.* 2015). Often SMEs do not have the necessary resources (in the form of human capacity and finance) to contribute to the research, development and demonstration of the OHS practices needed to address this problem (Legg *et al.* 2015). Some characteristics of SMEs make it extremely difficult for them to create and maintain a safe and healthy work environment, or to manage effectively with respect to safety issues (Targoutzidis *et al.* 2014).

The OHS challenges of developing country SMEs need to be researched more thoroughly so as to provide better inputs for SME policy design and legislative review. Limited information about these SMEs already shows that workers are more routinely exposed to hazardous situations and suffer more work-related injuries and illnesses than those in larger companies (Targoutzidis *et al.* 2014). Further research on the relation between injuries, accidents and the sizes of enterprises could help show how size matters in OHS management (Micheli and Cagno 2010).

## 6.3 Chemical risk management in the informal sector

### 6.3.1 Risk management challenges in the informal sector

#### The informal sector presents unique management challenges

The informal sector is usually characterized by small-scale activities that are not registered, taxed or monitored by any form of government authority, while the hundreds of millions of women and men who work in this sector often are poorly paid and carry out dangerous work (OECD 2002; Maiguashca 2016). More than 60 per cent the total global labour force is employed in the informal sector, and 93 per cent of informal employment is in emerging and developing countries (ILO 2018a). Despite a lack of detailed data on informal enterprises worldwide – and variations in the definitions of "informality" – it is clear that the number of these enterprises is very high and that a large share of all SMEs are in the informal sector (Charmes 2012; ILO 2015a). In Africa almost 86 per cent of employment is informal; the share is around 68 per cent in Asia and the Pacific, almost 69 per cent in the Arab States, 40 per cent in the Americas and about 25 per cent in Europe and Central Asia (ILO 2018a). People in rural areas are almost twice as likely to be in informal employment as those in urban areas: agriculture, where pesticides and other chemicals are widely and heavily used, has the highest level of informal employment, estimated at more than 90 per cent globally (ILO 2018a).

The production, consumption and disposal of chemicals can have external negative (spillover) impacts on individuals and firms outside these activities when they are not well managed. While informal and/or illegal behavior is often the source of chemicals pollution, by their nature it is unlikely that firms involved in these undertakings will take steps to internalize costs. Many such externalities can be reduced through responsible chemicals management (Hassan 2012; UNEP 2013).

A challenge for risk management in the informal sector is the lack of a clear overview of the nature, extent and location of informal activities/operations in countries. By definition, some or all aspects of informal economic activity are not included in the formal record and hence there is an information and statistics gap regarding these activities (Benjamin *et al*. 2014). This means the informal sector remains outside the scope of planned development and health and safety policies, as there is little information available to prioritize areas of prevention (Mukim 2011).

#### Limited knowledge about chemicals in the informal sector

Chemicals are used and handled in many informal activities in addition to agricultural ones, including cleaning, welding, construction, and employment in garages/workshops (Zock 2005; Ahmad *et al.* 2016). Informal workers are highly vulnerable to the health risks presented by the chemicals to which they are exposed daily due to poor working conditions, limited knowledge about chemical risks, high levels of exposure and lack of access to health care, among other factors (ILO 2018a; ILO 2018b; International Institute for Environment and Development 2018). Workers' level of education is important. Globally, when the level of education increases, the level of informality decreases; comparing national data on informal employment as a share of total employment with Human Development Index (HDI) values shows that countries with higher informality have a lower HDI value (ILO 2018a). The health impacts of working in informal enterprises range from skin irritation, respiratory allergies and asthma to acute poisonings, cancers and reproductive disorders (Rongo *et al.* 2004; Rockefeller Foundation 2013). Poor practices, such as failure to use personal protective measures or smoking at the workplace, are common in the informal sector and exacerbate the risks associated with chemical use (Rongo 2005).

Workers in the informal sector lack knowledge about chemical labelling and how to understand it. Furthermore, labels may be absent (Lajini 2014; Makhonge 2014). Actors in the informal sector are, however, obviously not exempt from legal requirements in a country and could be targeted by governments for information provision and inspections.

#### Lack of a safety and health culture

Since low-skilled and labour-intensive work in the informal sector is performed by people with low socio-economic status, they usually show greater readiness to accept dangerous working conditions. For example, waste pickers interviewed at the Mbeuebeuss waste dump in Senegal – some of whom were women, although many more were men – indicated that they had little choice but to undertake this type of work to survive despite the health risks to which they were exposed and the difficulty of obtaining health care (Vasina 2018)

#### Gender inequalities

Gender inequalities and child labour are common in informal activities (UNRISD 2010; ILO 2018a). In a globalized economy, women and children increasingly participate as wage earners. Among men, a higher share is employed in the informal sector than among women, both in developing and developed countries as well as in the agricultural and non-agricultural sector (ILO 2018a). However, the picture is heavily influenced by a few highly populous countries, as in low and lower-middle income countries the share of women informally employed exceeds that of men. Moreover, as the ILO concluded in its 2018 report, women in the informal economy are more vulnerable.

A study on female horticulture workers in Tanzania illustrates the chemical risk situation in informal agriculture. Women often bring their children to the fields because they lack access to or cannot afford day care services. The elder children help with work on the farm. Women and children often work in fields where pesticides are being applied. Further exposure (and that of other family members) can occur when contaminated clothes are washed in the household or even through pesticides stored in the kitchen or bedroom (Mrema *et al.* 2017).

#### Informal e-waste recycling

Recycling of metals found in waste (secondary production of metals) is growing rapidly worldwide. Metals such as aluminium, copper and gold can be recovered from e-waste (or electronic and electrical equipment waste). This activity is mainly carried out in the informal sector in developing and emerging countries such as China, Ghana, Brazil and India (e.g. 95 per cent of e-waste in India is treated and processed in the informal e-waste recycling sector) (Zheng *et al*. 2016; Chakraborty *et al.* 2018).

### 6.3.2 Policy challenges and opportunities

#### Formalization

ILO Recommendation No. 204 on transition from the informal to the formal economy acknowledges that most people enter the informal economy not by choice, but because of a lack of opportunities in the formal economy and an absence of any other means of livelihood. It provides strategies and practical guidance on policies and measures to facilitate the transition from the informal to the formal economy (ILO 2015b). The formalization of informal activities can contribute to better conditions for workers and achieve more inclusive and more sustainable development. In support of formalization, government regulations for licensing and registration may need to be made simpler and more practical. Measures also need to be tailored to specific circumstances in countries and to specific economic activities. An example related to chemicals is artisanal and small-scale gold mining (Box 6.2).

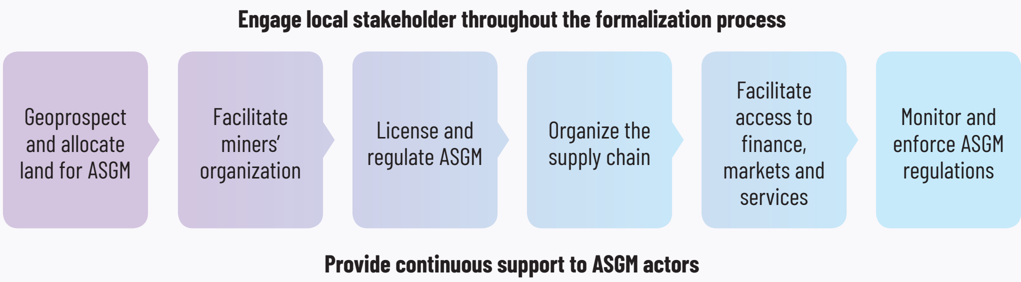
**Box 6.2** Formalizing artisanal and small-scale gold mining

Artisanal and small-scale gold mining (ASGM) has been estimated to provide direct employment for over 16 million people (approximately one-third are women) and accounts for up to 20 per cent of the world's gold production (Seccatore *et al.* 2014; Veiga, Angeloci-Santos and Meech 2014). Despite this sector's importance for socio-economic development, it has negative health and environmental impacts. For example, many ASGM miners use mercury to separate gold from sediment and ore. The resulting mixture of mercury and gold, or amalgam, is heated to vaporize the mercury and leave the gold behind, harming miners and their communities and contaminating the surrounding environment.

© UNITAR/Jordan De Haan, artisanal and small scale gold miner

Many of these challenges stem from the sector's typically informal nature, which deprives ASGM miners of access to financial and technical assistance, thereby perpetuating precarious working conditions and hindering the miners from adopting more sustainable mining practices. In recognition of this, the Minamata Convention on Mercury requires Parties with "more than insignificant ASGM activity" to develop National Action Plans (NAPs) for reducing mercury use in the sector, which should include "steps to facilitate the formalization or regulation" of the ASGM sector. Formalization is a process that seeks to integrate the ASGM sector into the formal economy, society and regulatory systems (UNEP 2012). If it is undertaken in a comprehensive and inclusive manner, formalization can help to address health and environmental impacts and unlock the sector's full development potential.

To support countries in undertaking such formalization efforts, the United Nations Institute for Training and Research and (UNITAR) and UNEP have prepared the *Handbook for Developing National ASGM Formalization Strategies within National Action Plans* (de Haan and Turner 2018). The Formalization Handbook provides a comprehensive introduction to ASGM formalization, including key concepts and terminology, key components of the formalization process, possible approaches and best practices. This is followed by step-by-step guidance for creating an enabling environment for ASGM formalization and developing a national strategy for formalizing the ASGM sector. Various issues and approaches are illustrated with case studies from developing countries. The Figure below shows the key components of the formalization process, which are discussed in detail in the Formalization Handbook.



### Extension of health insurance and other social services to workers in the informal sector

Despite the high risks they face, most Informal workers are not covered by social insurance. A number of countries have been looking at extending some form of social insurance to informal workers (ILO 1997; Thornton *et al.* 2010; Alfers 2013). With a few exceptions, most social protection policies remain gender-blind. Gender-responsive reforms could help ensure increased coverage of women, including informal workers. Not only do experiences of poverty and vulnerability differ for women and men, but women face life cycle risks that require particular attention and coverage from social insurance schemes (e.g. to reduce risks associated with childbirth). In addition, women may accept work in the informal sector while also performing paid or unpaid domestic and care work (Holmes and Scott 2016; Alfers, Lund and Moussié 2018).

### Multi-stakeholder engagement to promote occupational health and safety

The involvement of a number of different stakeholders is valuable for promoting occupational health and safety (OHS) among informal workers. For example, NGOs previously involved in communities of informal workers are likely to be well aware of the context of those communities and of needs in a specific sector. Moreover, personnel from NGOs, who may be seen as leaders by certain groups, can influence behavioural change to safer practices. The media are another group that could promote awareness and sensitize workers. Clear and correct messages should be designed with the media, so that they can be delivered to informal workers in an adequate and comprehensible way (Singh *et al*. 2011).

## 6.4 Potential measures to further advance risk management in facilities and during production

Leadership by decision-makers, industry responsibility, collaboration of actors in the supply chain, and increasing awareness and understanding among workers are crucial to prevent chemicals-related accidents and to facilitate sound chemicals and waste management, particularly in SMEs and in the informal sector. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance risk management in facilities and during production:

› Better integrate chemical accident prevention, preparedness and response into disaster risk management at all levels.

› Improve the understanding of risks and process safety in facilities, and strengthen information and knowledge-sharing on chemical accidents globally.

› Step up efforts to enhance access, awareness and understanding of relevant chemical hazard and safety information among workers, particularly in SMEs and in the informal sector.

› Encourage larger companies to work with SMEs in sharing knowledge about chemical risk management.

› Scale up capacity development measures through the supply chain in order to strengthen risk management capacity in the informal sector.

# 7/ Approaches to sustainability assessment

## Chapter Highlights

**Approaches that assess broader sustainability issues and potential trade-offs provide important complementary tools beyond assessing and managing the risks of chemicals.**

**Life cycle management is an approach increasingly used by companies to support more sustainability-focused supply chain risk management.**

**A host of life cycle assessment methods are available which allow wider sustainability assessment, and more such methods are under development.**

**Choices about when and how to use these methods need to be made, taking into account available capacities and resources, supply chain requirements and the regulatory context while avoiding "paralysis by analysis".**

In chemicals management the entire product life cycle has to be considered in order not only to take the human and environmental safety aspects of a chemical into account, but also to assess the wider sustainability parameters that can play a role. This chapter discusses the possible trade-offs that need to be made in this context by decision-makers and describes the tools which are available to assist them in this respect.

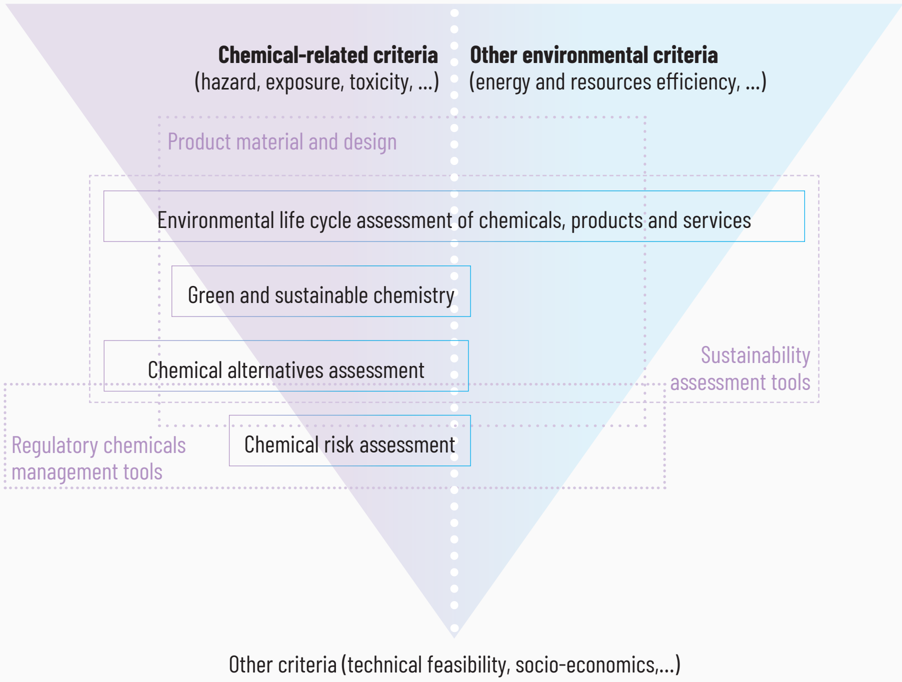
## 7.1 A holistic approach to assessing sustainability

A holistic life cycle approach allows comprehensive chemicals management with respect to various dimensions of sustainability. Not only does such an approach involve the assessment and management of the direct consumer and occupational risks of (groups of) chemicals. It also combines these risks with those from chemical exposure mediated via the environment. Considering all sustainability aspects at the design stage of a chemical or related product can make it possible to avoid overlooking certain trade-offs between sustainability impacts. It can also make it possible to avoid shifting the burden from one aspect of sustainability to another, or from the present to the future. Related requirements for policies, and for enabling relevant actors in the sustainable chemistry field, are addressed in Part IV. When chemicals are managed along entire product life cycles, attention needs to be paid to other factors which can have an impact on sustainability. These factors include materials extraction; energy and water use during chemical synthesis and product manufacturing; chemicals' occurrence and behaviour in waste streams; and the prospects of recycling chemicals for renewed use. Types of assessment frameworks that can be applied in chemical management are shown in Figure 7.1 (Fantke and Ernstoff 2018).

## 7.2 Assessing trade-offs between different impacts, locations and life cycle stages

As a complement to assessing and managing chemical risks in a regulatory or substitution context (discussed in previous chapters of Part III), there is a growing need for approaches and tools that allow the assessment of trade-

**Figure 7.1** Conceptual relationships of the main chemical management tools (adapted from Fantke and Ernstoff 2018, p. 787)






offs in the wider context of sustainability. An overview of such approaches is given in this chapter. They include assessing the direct human health and environmental risks of chemical exposures consistently with the full range of impacts – on humans and the environment while considering social aspects – which are related to the production and use of chemicals during their life cycle, from raw material extraction, via synthesis and manufacturing, to final use and end-of-life handling.

Such impacts include (but are not limited to) climate change impacts associated with greenhouse gas (GHG) emissions during oil refining; the formation of fine particulate matter and ozone from fuel combustion; the impacts on ecosystems of acidifying and eutrophying substances from agricultural emissions; energy use and emissions of harmful processing chemicals during chemical synthesis; and land and water use impacts of manufacturing and waste handling processes (Hauschild and Huijbregts 2015). The case for integrating the potential impacts of climate change as a consideration in assessments in general has been addressed, for example, in the US EPA *Climate Change Adaptation Implementation Plan,* which acknowledges the need to integrate the impacts of climate change into assessments insofar as these impacts could affect chemical safety (US EPA 2014).

Accounting for impacts in a wider sustainability context is key to progress in meeting the Sustainable Development Goals. Often certain types of impacts cannot be reduced without introducing trade-offs with others (this type of trade-off is sometimes referred to as "burden-shifting"). An example of burden-shifting is the move from petroleum-derived to bio-based polymers, which in most cases reduces GHG emissions but also results in soil degradation, toxicity and eutrophication if pesticides and fertilizers are not applied correctly in bio-feedstock production (Hottle, Biilec and Landis 2013). Burden-shifting may also occur between chemical life cycle stages. An example is the reduction of sourcing of virgin raw materials through increased recycling, which can result in exposure to harmful residues in recyclates (Pivnenko and Astrup 2016). It is important to look beyond impacts on, for example, workers, consumers or particular ecosystems and to assess all relevant impacts on humans and the environment during the entire chemical or product life cycle. At the same time, it is important to keep assessments practical – that is, focused on the most relevant impacts associated with the chemical-product combination being considered.

An adequate and sound assessment of chemicals-related sustainability will benefit from meeting the following criteria:

› The assessment offers a consistent basis for comparing human health and environmental risks with other types of impacts.

› It identifies relevant impact categories and sustainability metrics adapted to the application being considered, in order to limit effort and avoid being distracted by minor issues or negligible impacts.

› It covers all product and chemical life cycle stages.

› It is able to screen exposures and impacts of a large number of chemical-product combinations, considering chemical properties and product properties as well as people who will be exposed (e.g. workers, consumers and the general population).

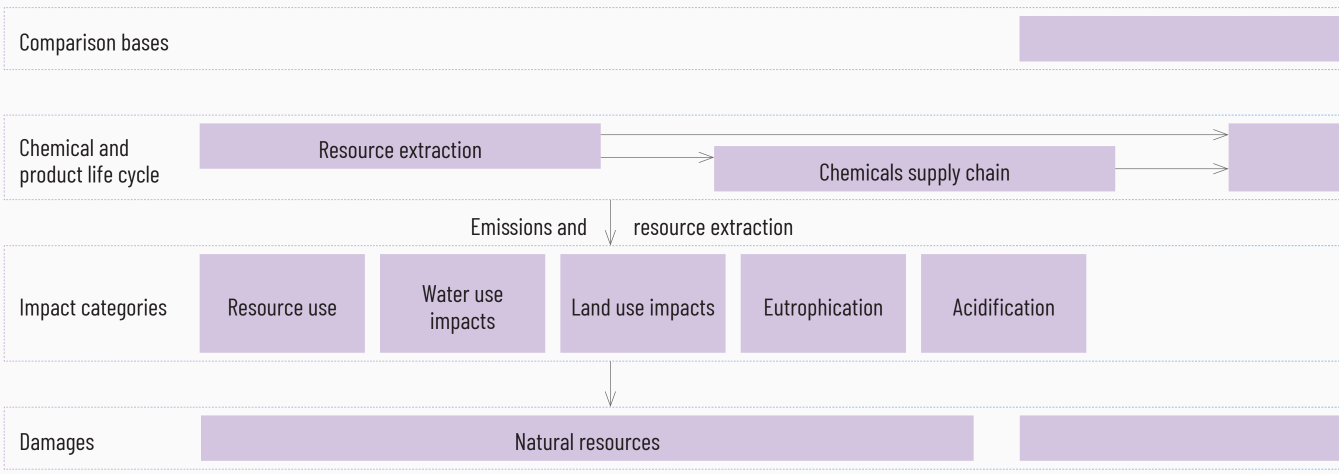
## 7.3 Sustainability assessment tools for chemicals

While certain sustainability assessment tools, such as carbon footprints and water footprints, adequately represent a company's environmental sustainability performance up to a point, these tools are restricted to particular areas of concern. They do not consider all relevant sustainability impacts in order to ensure overall minimized impacts on humans and the environment (Ridoutt *et al.* 2015). A change of perspective is therefore needed when looking at chemicals-related impacts.

To address the entire chemical or product life cycles in a wider sustainability context, several types of tools and methods exist that build on life cycle thinking. They range from political instruments, international agreements and international standards to procedural and analytical tools. Political instruments include regulations on supply chain and waste/end-of-life management or on integrated environmental management interventions. An example is the EU's Integrated Pollution Prevention and Control Directive 2010/75/EU (EC 2010).

International standards refer mainly to the International Organization for Standardization (ISO) 14000 family of environmental management standards (ISO 2018). Several of these standards are directly concerned with procedural and

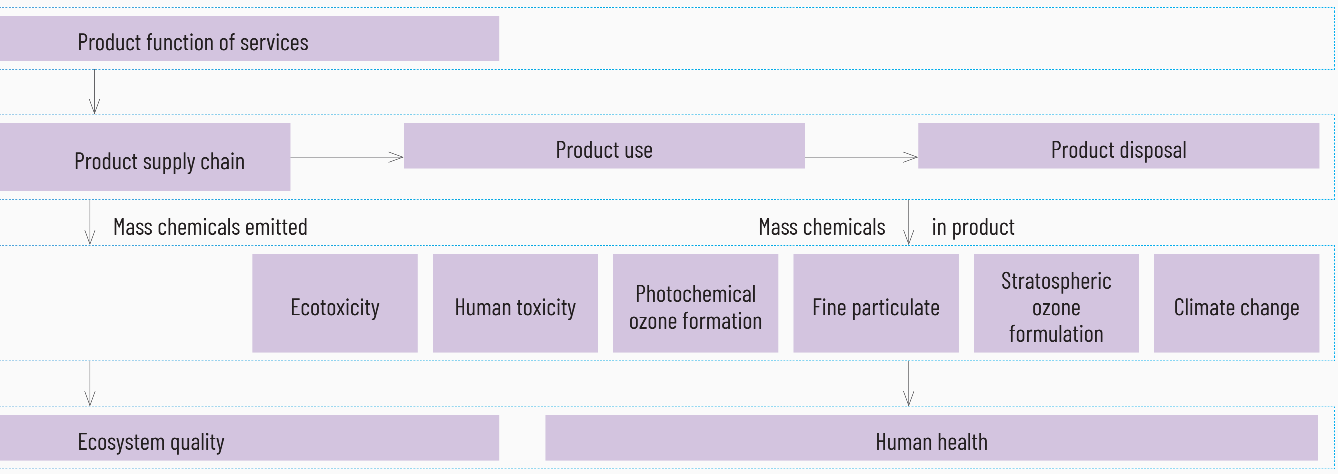
**Figure 7.2** General structure of the life cycle assessment (LCA) framework



analytical life cycle management (LCM) tools. LCM encourages a holistic management perspective. It covers the entire chemical or product life cycle and calls for managerial decisions that consider health and environmental impacts. LCM provides an opportunity to promote long-term achievements in order to minimize the environmental and socio-economic burden while maximizing economic and social value (Bey 2018). Applying a life cycle perspective is even more relevant in regard to advancing a circular economy, closing material loops along entire chemical and product life cycles and creating self-sustaining production systems. More specific procedural tools include, among others, eco-design (defined in ISO 14006), environmental labels and declarations (defined in the ISO 14020-14025 series) and environmental performance evaluation (defined in ISO 14030 and 14031). A method for assessing the economic, social and environmental sustainability performance of agricultural production at the farm level is the Response-Inducing Sustainability Evaluation (RISE) (Bern University of Applied Sciences 2017).

The most relevant analytical tool with a focus on the entire life cycle of chemicals and products is life cycle assessment (LCA), which is defined in the ISO 14040-14049 series (ISO 2018). The use of LCA to evaluate the environmental performance

**(Fantke *et al*. 2019, submitted)**



of products, services and technologies across sectors and countries has received increasing attention in the last two decades. Not only is LCA applied by individual companies. It is also being used as a method to evaluate 25 industry sectors in the context of the European pilot project series on the Product Environmental Footprint (PEF) and the Organization Environmental Footprint (OEF) (EC 2013).

LCA consists of four phases: goal and scope definition; life cycle inventory (LCI) analysis; life cycle impact assessment (LCIA); and interpretation. The LCI determines resources use, and chemical or pollutant emissions, based on a common product function. The LCIA phase focuses on characterizing the impacts of these LCI flows in several impact categories, such as global warming, human toxicity, ecotoxicity and water use (Figure 7.2). These impact categories cover three major areas of protection: human health; ecosystem quality; and natural resources (Verones *et al.* 2017). This allows not only assessing and comparing the different life cycle stages of a product or service, but also consistently assessing trade-offs between different impacts based on their relative damage (Hauschild 2005; Hellweg and Milà i Canals 2014).

## 7.4 Assessing chemicals' impacts in a life cycle-based comparative framework

When focusing on chemicals, it is important to assess their risks consistently with other types of impacts on human health and the environment. Several approaches, such as USEtox (Henderson *et al*. 2011; Rosenbaum *et al*. 2011), have been developed at the interface between risk assessment and LCA to adapt exposure and dose-response information for use within a comparative life cycle-based framework (Fantke *et al.* 2016).

Figure 7.3 shows the elements of such a comprehensive framework for evaluating chemicals and products in the global supply chain and their potential impacts on humans and the environment. Key elements include:

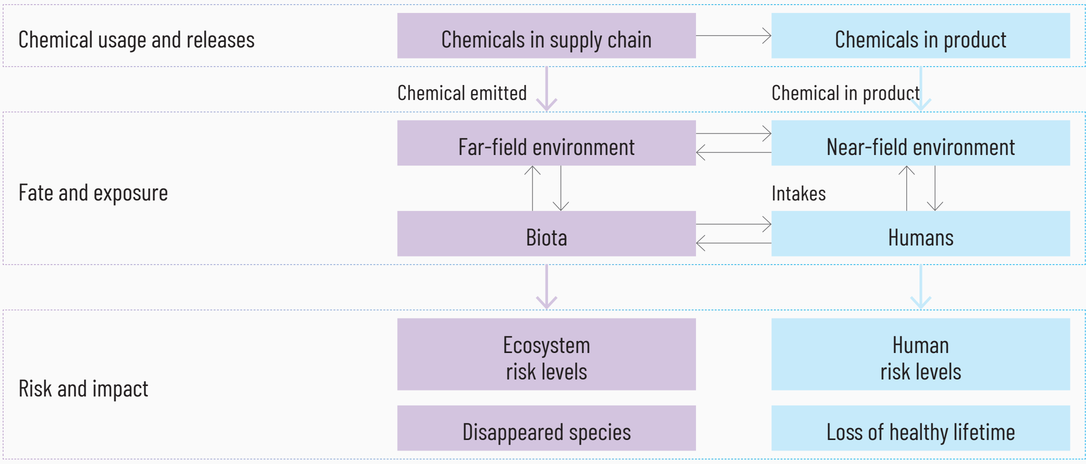
- quantifying during the product life cycle – to the extent possible – the chemical use and the mass emitted to the far-field environment within the supply chain, or the chemical mass that enters a defined compartment of entry in the consumer's near-field environment;
- capturing fate and exposure processes that result in transfers of chemicals between any near-field compartments (e.g. indoor air, the inside of objects) and far-field compartments (e.g. freshwater, ambient air) until finally reaching biota or humans;
- combining human intake via all relevant exposure pathways with dose-response, severity or other hazard information to assess risk or impact levels; and
- combining environmental concentrations with concentration-response information to assess related fractions of species that have disappeared or are affected due to chemical exposure in different environmental compartments (Verones *et al*. 2017).

In addition, for chemicals-based assessment not all impact categories are equally important. There is a need for a screening-level assessment of alternatives, which (where possible) is quantitative, life cycle-based, and able to serve both life cycle assessment (LCA) and chemical alternatives assessment (CAA). Such a life cycle-based alternatives assessment needs to quantify exposure and life cycle impacts consistently and efficiently over the main life cycle stages, avoiding "paralysis by analysis" in order to meet the time constraints of a screening assessment while ensuring scientific rigour (Fantke *et al*. 2019).

### Strategic life cycle assessment: also considering socio-ecological sustainability

Tools such as The Natural Step's Strategic Life Cycle Assessment (SLCA) can be used to provide an overview of the full scope of sustainability at the product level. SLCA is an effective approach for assessment, capacity building and innovation within and beyond individual organizations (The Natural Step [TNS] 2018). It goes beyond inherent chemical or product properties and

**Figure 7.3** Elements of a comprehensive framework to evaluate global chemical supply chain impacts on humans and the environment (based on Fantke *et al.* 2016, p. 510)




their potential exposures, which are commonly looked at, by connecting the product to science-based conditions for social and ecological sustainability (Ny *et al.* 2006). The principles and qualitative approach of SLCA encourage thinking strategically about the management of chemicals and waste in a broader context. They can stimulate innovation to prevent regrettable substitutions and burden-shifting in a circular economy (TNS 2018).

## 7.5 Potential measures to further advance approaches to sustainability assessment

Stakeholders may find value in the further development and use of wider sustainability assessment methods, including life cycle assessment tools, while acknowledging that informed choices have to be made about when and how to use these methodologies. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance approaches to sustainability assessment:

- During the chemical risk management decision-making process, consider the need to identify potential trade-offs in a wider sustainability context.
- In considering the benefits of sustainability assessment methods, take into account regulatory priorities and resource considerations, while avoiding "paralysis by analysis" through focusing on the most relevant sustainability aspects.
- Scale up the further development and use of life cycle assessment tools and life cycle management practices across sectors.

# References

## Chapter 1

American Chemical Society (2018). Definitions of hazard assessment. https://www.acs.org/content/acs/en/about/governance/committees/chemicalsafety/hazard-assessment/tools/definitions.html. Accessed 31 May 2018.

Berggren, E., Amcoff, P., Benigni, R., Blackburn, K., Carney, E., Cronin, M., Deluyker, H., Gautier, F., Judson, R.S., Kass, G.E.N., Keller, D., Knight, D., Lilienblum, W., Mahony, C., Rusyn, I., Schultz, T., Schwarz, M., Schüürmann, G., White, A., Burton, J., Lostia, A.M., Munn, S. and Worth, A. (2015). Chemical safety assessment using read-across: assessing the use of novel testing methods to strengthen the evidence base for decision making. *Environmental Health Perspectives* 123(12), 1232-1240. https://doi.org/10.1289/ehp.1409342.

Beronius, A., Hanberg, A., Zilliacus, J. and Rudén, C. (2014). Bridging the gap between academic research and regulatory health risk assessment of Endocrine Disrupting Chemicals. *Current Opinion in Pharmacology* 19, 99-104. https://doi.org/10.1016/J.COPH.2014.08.005.

Chemical Inspection and Regulation Service (2012a). Korea Toxic Chemicals Control Act (TCCA). http://www.cirs-reach.com/KoreaTCCA/Korea_Toxic_Chemicals_Control_Act_TCCA.html. Accessed 31 May 2018.

Chemical Inspection and Regulation Service (2012b). Turkish REACH-like chemical regulation. http://www.cirs-reach.com/Turkey/Turkey_Chemical_Regulation_Inventory_and_Control_of_Chemicals.html. Accessed 31 May 2018.

Chemical Inspection and Regulation Service (2017). MEP revised the data requirements under guidance documents for new chemical substance notification in China, 8 July. http://www.cirs-reach.com/news-and-articles/MEP-Revised-the-Data-Requirements-under-Guidance-Documents-for-New-Chemical-Substance-Notification-in-China.html. Accessed 30 December 2018.

ChemSafetyPro (2017). How to comply with Chemicals Control Act (CCA) in Korea. https://www.chemsafetypro.com/Topics/Korea/Introduction_to_Korean_Chemicals_Control_Act.html. Accessed 23 August 2018.

ChemSafetyPro (2018). How to Comply with Amended K-REACH Regulation 2018. https://www.chemsafetypro.com/Topics/Korea/Korea_REACH.html. Accessed 30 December 2018.

Colaianna, M., Ilmjärv, S., Peterson, H., Kern, I., Julien, S., Baquié, M., Pallocca, G., Bosgra, S., Sachinidis, A., Hengstler, J.G., Leist, M. and Krause, K.-H. (2017). Fingerprinting of neurotoxic compounds using a mouse embryonic stem cell dual luminescence reporter assay. *Archives of Toxicology* 91(1), 365-391. https://doi.org/10.1007/s00204-016-1690-2.

Cynober, T. (2018). Could stem cells replace animal testing in drug development? 14 May. https://labiotech.eu/animal-testing-stem-cells/. Accessed 9 June 2018.

Delrue, N., Sachana, M., Sakuratani, Y., Gourmelon, A., Leinala, E. and Diderich, R. (2016). The adverse outcome pathway concept: a basis for developing regulatory decision-making tools. *Alternatives to Laboratory Animals* 44(5), 417-429. http://www.ncbi.nlm.nih.gov/pubmed/27805824.

Dimitrov, S.D., Diderich, R., Sobanski, T., Pavlov, T.S., Chankov, G. V., Chapkanov, A.S., Karakolev, Y.H., Temelkov, S.G., Vasilev, R.A., Gerova, K.D., Kuseva, C.D., Todorova, N.D., Mehmed, A.M., Rasenberg, M. and Mekenyan, O.G. (2016). QSAR Toolbox – workflow and major functionalities. *SAR and QSAR in Environmental Research* 27(3), 203-219. https://doi.org/10.1080/1062936X.2015.1136680.

Environment and Climate Change Canada (2016). *Chemicals Management Plan (CMP) Science Committee Objectives Paper: Meeting No. 5; 16-17 November 2016. Integrating New Approach Methodologies within the CMP: Identifying Priorities for Risk Assessment, Existing Substances Risk Assessment Program*. http://www.ec.gc.ca/ese-ees/172614CE-D9F6-43DA-A528-B8175438210F/Objectives%20Paper%20November%202016_EN.pdf.

European Chemical Industry Council Long-Range Research Initiative (2017). AMBIT. http://cefic-lri.org/toolbox/ambit/. Accessed 4 August 2018.

European Chemicals Agency (2016a). *Chemicals Presenting Priority Setting Challenges (2016) Presentation by M. Rasenberg at the OECD Working Party on Hazard Assessment*. Paris.

European Chemicals Agency (2016b). *ECHA's Ambition Towards 2025*. Helsinki. https://echa.europa.eu/documents/10162/2200151/mb_46_2016_echa_ambition_towards_2025_incl_annex_en.pdf/45c509e5-5ed3-bdb7-7515-3a6dbca9d727

European Chemicals Agency (2017a). Endpoint specific guidance. In *Guidance on information requirements and chemical safety assessment*. Chapter T. 7a. 1-610. https://doi.org/10.2823/337352.

European Chemicals Agency (2017b). *Non-Animal Approaches – Current Status of Regulatory Applicability Under the REACH, CLP and Biocidal Products Regulations*. https://echa.europa.eu/documents/10162/22931011/non_animal_approcches_en.pdf/87ebb68f-2038-f597-fc33-f4003e9e7d7d.

European Chemicals Agency (2017c) *Guidance on Information Requirements and Chemical Safety Assessment. Appendix R.6-1 for Nanomaterials Applicable to the Guidance on QSARs and Grouping of Chemicals.* Version 1.0. https://echa.europa.eu/documents/10162/23036412/appendix_r6_nanomaterials_en.pdf/71ad76f0-ab4c-fb04-acba-074cf045eaaa.

European Chemicals Agency (2017d). *The Use of Alternatives to Testing on Animals for the REACH Regulation*. https://echa.europa.eu/documents/10162/13639/alternatives_test_animals_2017_en.pdf.

European Chemicals Agency (2017e). Guest column: are REACH data appropriate for hazard identification and risk assessment? ECHA Newsletter No. 4, November. https://newsletter.echa.europa.eu/home/-/newsletter/entry/guest-column-are-reach-data-appropriate-for-hazard-identification-and-risk-assessment-. Accessed 1 January 2019.

European Chemicals Agency (2018). New database on Candidate List substances in articles by 2021, 11 July. https://echa.europa.eu/nl/-/new-database-on-candidate-list-substances-in-articles-by-2021. Accessed 30 December 2018.

European Chemicals Agency (n.d. a). REACH legislation. https://echa.europa.eu/regulations/reach/legislation. Accessed 4 August 2018.

European Chemicals Agency (n.d. b). Search for chemicals. https://echa.europa.eu/information-on-chemicals. Accessed 30 December 2018.

European Chemicals Agency (n.d. c). Chesar: Chemical safety assessment and reporting tool. https://chesar.echa.europa.eu/. Accessed 24 August 2018.

European Chemicals Agency and Organisation for Economic Co-operation and Development (2018). IUCLID 6. https://iuclid6.echa.europa.eu/. Accessed 1 August 2018.

European Chemicals Agency and United States Environmental Protection Agency (2016). *ECHA-EPA Workshop: Accelerating the Pace for (Chemical) Risk Assessment (APCRA)*. https://ntp.niehs.nih.gov/ntp/about_ntp/bsc/2017/december/meetingmaterials/bucher_echa_508.pdf.

European Commission (2006). Regulation (EC) No. 1907/2006 of the European parliament and of the council of 18 December 2006 concerning the registration, evaluation, authorisation and restriction of chemicals (REACH), establishing a European chemicals agency, amending directive 1999. *Official Journal of the European Union* L 396, 3-280. https://doi.org/10.04.2014.

European Commission (2018). Nanomaterials in REACH and CLP. http://ec.europa.eu/environment/chemicals/nanotech/reach-clp/index_en.htm. Accessed 1 January 2019.

Gottardo, S., Alessandrelli, M., Amenta, V., Atluri, R., Barberio, G., Bekker, C., Bergonzo, P., Bleeker, E., Booth, A.M., Borges, T., Buttol, P., Carlander, D., Castelli, S., Chevillard, S., Clavaguera, S., Dekkers, S., Delpivo, C., Di Prospero Fanghella, P., Dusinska, M., Einola, J., Ekokoski, E., Fito, C., Gouveia, H., Grall, R., Hoehener, K., Johanson, G., Laux, P., Lehmann, Hans Christian. Leinonen, R., Mech, A., Micheletti, Christian. Noorlander, C., Olof-Mattsson, M., Oomen, A., Quiros Pesudo, L., Polci, M.L. and Prina-Mello, Adriele., Rasmussen, K., Rauscher, H., Sanchez Jimenez, A., Riego Sintes, J., Scalbi, S., Sergent, J.-A., Stockmann-Juvala, H., Simko, M., Sips, A., Suarez, B., Sumrein, A., van Tongeren, M., Vazquez, S., Vital, N., Walser, T., Wijnhoven, S. and Crutzen, H. (2017). *NANoREG Framework for the Safety Assessment of Nanomaterials*. Gottardo, S., Crutzen, H. and Jantunen, P. (eds.). Ispra: Publications Office of the European Union. https://doi.org/10.2760/245972.

Government of Canada (2016a). Chemicals management plan, 2 June. https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan.html. Accessed 1 January 2019.

Government of Canada (2016b). Substance groupings initiative, 8 October. https://www.canada.ca/en/health-canada/services/chemical-substances/substance-groupings-initiative.html. Accessed 1 January 2019.

Government of Canada (2017). Chemicals management plan science committee: Mid-term progress report February 2014 – June 2015, 13 October. https://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=8823FEF0-1#toc7b. Accessed 1 January 2019.

He, N. (2019). South Korea issues 364 CMR substances for reporting by 2021, 1 January. *Chemlinked*. https://chemlinked.com/news/chemical-news/south-korea-issues-364-cmr-substances-registration-2021. Accessed 3 January 2019.

International Labour Organization (2018). International chemical safety cards. http://www.ilo.org/safework/info/publications/WCMS_113134/lang--en/index.htm. Accessed 1 January 2019.

Japan Ministry of Economy, Trade and Industry (2016). What is CSCL (Chemical Substances Control Law), 4 March. http://www.meti.go.jp/policy/chemical_management/english/cscl/about.html. Accessed 1 January 2019.

Jeliazkova, N., Koch, V., Li, Q., Jensch, U., Reigl, J.S., Kreiling, R., Georgiev, I. and Hubesch, B. (2016). Linking LRI AMBIT chemoinformatic system with the IUCLID substance database to support read-across of substance endpoint data and category formation. *Toxicology Letters* 258, 114-115. https://doi.org/10.1016/j.toxlet.2016.06.1469.

Krewski, D., Acosta, D., Andersen, M., Anderson, H., Bailar, J.C., Boekelheide, K., Brent, R., Charnley, G., Cheung, V.G., Green, S., Kelsey, K.T., Kerkvliet, N.I., Li, A.A., McCray, L., Meyer, O., Patterson, R.D., Pennie, W., Scala, R.A., Solomon, G.M., Stephens, M., Yager, J. and Zeise, L. (2010). Toxicity testing in the 21st century: a vision and a strategy. *Journal of Toxicology and Environmental Health. Part B, Critical Reviews* 13, 51-138. https://doi.org/10.1080/10937404.2010.483176.

Lexology (2018). What's new with China's chemical import and export regulatory programs, 21 February. https://www.lexology.com/library/detail.aspx?g=a1ebde22-4b14-4d09-8ca3-c9878028a444. Accessed 1 January 2019.

Maertens, A., Anastas, N., Spencer, P.J., Stephens, M., Goldberg, A. and Hartung, T. (2014). Green toxicology. *Alternatives to Animal Experimentation* 31(3), 243-249. http://www.ncbi.nlm.nih.gov/pubmed/25061898.

Organisation for Economic Co-operation and Development (2003). *Descriptions of Selected Key Generic Terms Used in Chemical Hazard/Risk Assessment*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2003)15&docLanguage=En.

Organisation for Economic Co-operation and Development (2005). *Guidance Document on the Validation and International Acceptance of New or Updated Test Methods for Hazard Assessment*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=env/jm/mono(2005)14.

Organisation for Economic Co-operation and Development (2007). *Guidance Document on the Validation of (Quantitative) Structure-Activity Relationships*. http://www.oecd.org/fr/securitechimique/risques/38130292.pdf.

Organisation for Economic Co-operation and Development (2010). *Cutting Costs in Chemicals Management: How OECD Helps Governments and Industry*. https://doi.org/10.1787/9789264085930-en.

Organisation for Economic Co-operation and Development (2014a). *Guidance on Grouping of Chemicals*. 2nd edn. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2014)4&doclanguage=en.

Organisation for Economic Co-operation and Development (2014b). *New Guidance Document on an Integrated Approach on Testing and Assessment (IATA) for Skin Corrosion and Irritation*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2014)19&doclanguage=en.

Organisation for Economic Co-operation and Development (2016). *Report on the Pilot Project on Assessing the Potential Development of a Global List of Classified Chemicals*. https://one.oecd.org/document/ENV/JM/MONO(2016)43/en/pdf.

Organisation for Economic Co-operation and Development (2017). *Guidance Document for the Use of Adverse Outcome Pathways in Developing Integrated Approaches to Testing and Assessment (IATA)*. https://issuu.com/oecd.publishing/docs/guidance_document_for_the_use_of_ad.

Organisation for Economic Co-operation and Development (2018a). Safety of manufactured nanomaterials. http://www.oecd.org/science/nanosafety/. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018b). OECD guidelines for the testing of chemicals, section 1: physical-chemical properties. https://www.oecd-ilibrary.org/environment/oecd-guidelines-for-the-testing-of-chemicals-section-1-physical-chemical-properties_20745753. Accessed 1 January 2019

Organisation for Economic Co-operation and Development (2018c). OECD guidelines for the testing of chemicals, section 2: effects on biotic systems. https://www.oecd-ilibrary.org/environment/oecd-guidelines-for-the-testing-of-chemicals-section-2-effects-on-biotic-systems_20745761. Accessed 1 January 2019

Organisation for Economic Co-operation and Development (2018d). *OECD guidelines for the testing of chemicals, section 3*: environmental fate and behaviour. https://www.oecd-ilibrary.org/environment/oecd-guidelines-for-the-testing-of-chemicals-section-3-degradation-and-accumulation_2074577x. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018e). OECD guidelines for the testing of chemicals, section 4: health effects. https://www.oecd-ilibrary.org/environment/oecd-guidelines-for-the-testing-of-chemicals-section-4-health-effects_20745788. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018f). Good laboratory practice (GLP). http://www.oecd.org/chemicalsafety/testing/good-laboratory-practiceglp.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018g). OECD test guidelines for the chemicals. http://www.oecd.org/chemicalsafety/testing/oecdguidelinesforthetestingofchemicals.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018h). Mutual acceptance of data (MAD). http://www.oecd.org/chemicalsafety/testing/mutualacceptanceofdatamad.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018i). Animal welfare: OECD considers animal welfare in the development of test guidelines. http://www.oecd.org/chemicalsafety/testing/animal-welfare.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018j). The OECD QSAR toolbox. http://www.oecd.org/chemicalsafety/risk-assessment/oecd-qsar-toolbox.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (n.d.). The global portal to information on chemical substances. *eChemPortal*. https://www.echemportal.org/echemportal/index.action. Accessed 1 January 2019

Parliament of the Commonwealth of Australia (2017). Industrial Chemicals Bill 2017. https://www.aph.gov.au/Parliamentary_Business/Bills_Legislation/Bills_Search_Results/Result?bId=r5885. Accessed 1 January 2019.

Persson, L., Karlsson-Vinkhuyzen, S., Lai, A., Persson, Å. and Fick, S. (2017). The globally harmonized system of classification and labelling of chemicals: explaining the legal implementation gap. *Sustainability* 9(12), 1-21. https://doi.org/10.3390/su9122176.

SGS (2017). Turkey publishes EU REACH-like regulation, 7 July. https://www.sgs.com/en/news/2017/07/safeguards-10217-turkey-publishes-eu-reach-like-regulation. Accessed 1 January 2019

Swedish Chemicals Agency (2018). PRIO – a tool for risk reduction of chemicals. Hazard assessment. https://www.kemi.se/en/prio-start/chemicals-in-practical-use/hazard-assessment. Accessed 1 January 2019.

United Nations (2017). *Globally Harmonised System for Classification and Labelling of Chemicals (GHS)*. 7th revised edn. New York and Geneva. ST/SG/AC.10/30/Rev.7. https://www.unece.org/fileadmin/DAM/trans/danger/publi/ghs/ghs_rev07/English/ST_SG_AC10_30_Rev7e.pdf. Accessed 31 May 2018.

United Nations Economic Commission for Europe (n.d.). GHS implementation. https://www.unece.org/trans/danger/publi/ghs/implementation_e.html. Accessed 1 January 2019.

United States Environmental Protection Agency (2010). *TSCA New Chemicals Program (NCP) Chemical Categories.* https://www.epa.gov/sites/production/files/2014-10/documents/ncp_chemical_categories_august_2010_version_0.pdf.

United States Environmental Protection Agency (2016). Research on nanomaterials, 18 October. https://www.epa.gov/chemical-research/research-nanomaterials. Accessed 1 January 2019.

United States Environmental Protection Agency (2017). Endocrine Disruptor Screening Program (EDSP) Overview, 22 February. https://www.epa.gov/endocrine-disruption/endocrine-disruptor-screening-program-edsp-overview. Accessed 1 January 2019.

United States Environmental Protection Agency (2018a). Legislative and regulatory authority for reviewing new chemicals under TSCA, 15 November. https://www.epa.gov/reviewing-new-chemicals-under-toxic-substances-control-act-tsca/legislative-and-regulatory-authority. Accessed 1 January 2019.

United States Environmental Protection Agency (2018b). The Frank R. Lautenberg Chemical Safety for the 21st Century Act. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/frank-r-lautenberg-chemical-safety-21st-century-act. Accessed 1 January 2019.

United States Environmental Protection Agency (2018c). Exploring ToxCast data: downloadable data. https://www.epa.gov/chemical-research/toxicity-forecaster-toxcasttm-data. Accessed 1 January 2019.

Unites States Environmental Protection Agency (2018d) *Strategic Plan to Promote the Development and Implementation of Alternative Test Methods Within the TSCA Program.* https://www.epa.gov/sites/production/files/2018-06/documents/epa_alt_strat_plan_6-20-18_clean_final.pdf.

United States Environmental Protection Agency (2018e). Alternative test methods and strategies to reduce vertebrate animal testing. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/alternative-test-methods-and-strategies-reduce. Accessed 1 January 2019.

United States Interagency Coordinating Committee on the Validation of Alternative Methods (2018). *A Strategic Roadmap for Establishing New Approaches to Evaluate the Safety of Chemicals and Medical Products in the United States.* https://dx.doi.org/10.22427/NTP-ICCVAM-ROADMAP2018.

United States National Academy of Sciences (2007). *Toxicity Testing in the 21st Century: A Vision and a Strategy*. https://www.nap.edu/catalog/11970/toxicity-testing-in-the-21st-century-a-vision-and-a.

United States National Library of Medicine (2018). Hazard identification. *ToxTutor*. https://toxtutor.nlm.nih.gov/06-002.html. Accessed 1 January 2019.

Vinken, M., Knapen, D., Vergauwen, L., Hengstler, J.G., Angrish, M. and Whelan, M. (2017). Adverse outcome pathways: a concise introduction for toxicologists. *Archives of Toxicology* 91(11), 3697-3707. https://doi.org/10.1007/s00204-017-2020-z.

Wexler, P., Judson, R., de Marcellus, S., de Knecht, J. and Leinala, E. (2016). Health effects of toxicants: online knowledge support. *Life Sciences* 145, 284-293. https://doi.org/10.1016/J.LFS.2015.10.002.

World Health Organization (2019). International programme on chemical safety: international chemical safety cards. http://www.who.int/ipcs/publications/icsc/en/. Accessed 3 January 2019.

## Chapter 2

Altenburger, R., Backhaus, T., Boedeker, W., Faust, M. and Scholze, M. (2013). Simplifying complexity: mixture toxicity assessment in the last 20 years. *Environmental Toxicology and Chemistry* 32(8), 1685-1687. https://doi.org/10.1002/etc.2294.

Aylward, L.L., Green, E., Porta, M., Toms, L.-M., Den Hond, E., Schulz, C., Gasull, M., Pumarega, J., Conrad, A., Kolossa-Gehring, M., Schoeters, G. and Mueller, J.F. (2014). Population variation in biomonitoring data for persistent organic pollutants (POPs): an examination of multiple population-based datasets for application to Australian pooled biomonitoring data. *Environment International* 68, 127-138. https://doi.org/10.1016/J.ENVINT.2014.03.026.

Becker, K., Seiwert, M., Casteleyn, L., Joas, R., Joas, A., Biot, P., Aerts, D., Castaño, A., Esteban, M., Angerer, J., Koch, H.M., Schoeters, G., Hond, E. Den, Sepai, O., Exley, K., Knudsen, L.E., Horvat, M., Bloemen, L. and Kolossa-Gehring, M. (2014). A systematic approach for designing a HBM pilot study for Europe. *International Journal of Hygiene and Environmental Health* 217(2-3), 312-322. https://doi.org/10.1016/J.IJHEH.2013.07.004.

Cohen Hubal, E.A., Richard, A., Aylward, L., Edwards, S., Gallagher, J., Goldsmith, M.-R., Isukapalli, S., Tornero-Velez, R., Weber, E. and Kavlock, R. (2010). Advancing exposure characterization for chemical evaluation and risk assessment. *Journal of Toxicology and Environmental Health, Part B* 13(2-4), 299-313. https://doi.org/10.1080/10937404.2010.483947.

Consortium to Perform Human Biomonitoring on a European Scale (2016). Human biomonitoring. http://www.eu-hbm.info/cophes/human-biomonitoring. Accessed 2 January 2019.

Csiszar, S.A., Ernstoff, A.S, Fantke, P. and Jolliet, O. (2017). Stochastic modeling of near-field exposure to parabens in personal care products. *Journal of Exposure Science and Environmental Epidemiology* 27(2), 152-159. http://doi.org/10.1038/jes.2015.85.

Csiszar, S.A., Ernstoff, A.S., Fantke, P., Meyer, D.E. and Jolliet, O. (2016). High-throughput exposure modeling to support prioritization of chemicals in personal care products. *Chemosphere* 163, 490-498. https://doi.org/10.1016/J.CHEMOSPHERE.2016.07.065.

Di Guardo, A., Gouin, T., MacLeod, M. and Scheringer, M. (2018). Environmental fate and exposure models: advances and challenges in 21st century chemical risk assessment. *Environmental Science: Processes & Impacts* 20(1), 58-71. https://doi.org/10.1039/C7EM00568G.

Escher, B.I., Hackermüller, J., Polte, T., Scholz, S., Aigner, A., Altenburger, R., Böhme, A., Bopp, S.K., Brack, W., Busch, W., Chadeau-Hyam, M., Covaci, A., Eisenträger, A., Galligan, J.J., Garcia-Reyero, N., Hartung, T., Hein, M., Herberth, G., Jahnke, A., Kleinjans, J., Klüver, N., Krauss, M., Lamoree, M., Lehmann, I., Luckenbach, T., Miller, G.W., Müller, A., Phillips, D.H., Reemtsma, T., Rolle-Kampczyk, U., Schüürmann, G., Schwikowski, B., Tan, Y.-M., Trump, S., Walter-Rohde, S. and Wambaugh, J.F. (2017). From the exposome to mechanistic understanding of chemical-induced adverse effects. *Environment International* 99, 97-106. https://doi.org/10.1016/J.ENVINT.2016.11.029.

European Chemicals Agency (2016). Environmental exposure assessment. In *Guidance on Information Requiremets and Chemical Safety Assessment*. Chapter R.16. 1-178. https://echa.europa.eu/documents/10162/13632/information_requirements_r16_en.pdf.

European Chemicals Agency (2018a). Chesar: chemical safety assessment and reporting tool. https://chesar.echa.europa.eu/. Accessed 30 December 2018.

European Chemicals Agency (2018b). Workshop on EUSES update needs. https://echa.europa.eu/nl/-/workshop-on-euses-update-needs. Accessed 30 December 2018.

European Commission (2018) Information platform for chemical monitoring: enhancing access to chemical data, 10 March. https://ipchem.jrc.ec.europa.eu/RDSIdiscovery/ipchem/index.html. Accessed 30 December 2018.

Fantke, P., Ernstoff, A.S., Huang, L., Csiszar, S.A. and Jolliet, O. (2016). Coupled near-field and far-field exposure assessment framework for chemicals in consumer products. *Environment International* 94, 508-518. https://doi.org/10.1016/j.envint.2016.06.010.

Faustman, E.M. and Omenn, G.S. (2013). Risk assessment. In *Casarett and Doull's Toxicology: The Basic Science of Poisons*. 8th edn. Klaassen, C.D. (ed.). McGraw-Hill Education. Chapter 4. 123-149. https://accesspharmacy.mhmedical.com/content.aspx?sectionid=53483723&bookid=958.

Gligorovski, S. and Abbatt, J.P.D. (2018). An indoor chemical cocktail. *Science* 359(6376), 632-633. https://doi.org/10.1126/science.aar6837.

Goldsmith, M.-R., Grulke, C.M., Brooks, R.D., Transue, T.R., Tan, Y.M., Frame, A., Egeghy, P.P., Edwards, R., Chang, D.T., Tornero-Velez, R., Isaacs, K., Wang, A., Johnson, J., Holm, K., Reich, M., Mitchell, J., Vallero, D.A., Phillips, L., Phillips, M., Wambaugh, J.F., Judson, R.S., Buckley, T.J. and Dary, C.C. (2014). Development of a consumer product ingredient database for chemical exposure screening and prioritization. *Food and Chemical Toxicology* 65, 269-279. https://doi.org/10.1016/J.FCT.2013.12.029.

Government of Canada (2018). Canadian health measures survey, 23 August. https://www.statcan.gc.ca/eng/survey/household/5071. Accessed 24 August 2018.

Heffernan, A.L., Aylward, L.L., Toms, L.-M.L., Sly, P.D., Macleod, M. and Mueller, J.F. (2014). Pooled biological specimens for human biomonitoring of environmental chemicals: opportunities and limitations. *Journal of Exposure Science & Environmental Epidemiology* 24(3), 225-232. https://doi.org/10.1038/jes.2013.76.

Heffernan, A.L., Baduel, C., Toms, L.M.L., Calafat, A.M., Ye, X., Hobson, P., Broomhall, S. and Mueller, J.F. (2015). Use of pooled samples to assess human exposure to parabens, benzophenone-3 and triclosan in Queensland, Australia. *Environment International* 85, 77-83. https://doi.org/10.1016/J.ENVINT.2015.09.001.

Human and Environmental Risk Assessment (n.d.). HERA Initiative. https://www.heraproject.com/Initiative.cfm. Accessed 30 December 2018.

Human Biomonitoring for Europe (2018). About HBM4EU. https://www.hbm4eu.eu/about-hbm4eu/. Accessed 30 December 2018.

International Labour Organization (1993). *Safety in the Use of Chemicals at work: An ILO Code of Practice*. https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/normativeinstrument/wcms_107823.pdf.

International Labour Organization (2004). Monitoring in the workplace, 30 November. https://www.ilo.org/legacy/english/protection/safework/cis/products/safetytm/chemcode/12.htm. Accessed 24 August 2018.

International Labour Organization (2011). Chemical exposure limits, 16 February. https://www.ilo.org/safework/info/publications/WCMS_151534/lang--en/index.htm. Accessed 24 August 2018.

Isaacs, K.K., Glen, W.G., Egeghy, P., Goldsmith, M.-R., Smith, L., Vallero, D., Brooks, R., Grulke, C.M. and Özkaynak, H. (2014). SHEDS-HT: an integrated probabilistic exposure model for prioritizing exposures to chemicals with near-field and dietary sources. *Environmental Science & Technology* 48(21), 12750-12759. https://doi.org/10.1021/es502513w.

Isaacs, K.K., Goldsmith, M.-R., Egeghy, P., Phillips, K., Brooks, R., Hong, T. and Wambaugh, J.F. (2016). Characterization and prediction of chemical functions and weight fractions in consumer products. *Toxicology Reports* 3, 723-732. https://doi.org/10.1016/J.TOXREP.2016.08.011.

Kijko, G., Jolliet, O. and Margni, M. (2016). Occupational health impacts due to exposure to organic chemicals over an entire product life cycle. *Environmental Science & Technology* 50(23), 13105-13114. https://doi.org/10.1021/acs.est.6b04434.

Kijko, G., Margni, M., Partovi-Nia, V., Doudrich, G. and Jolliet, O. (2015). Impact of occupational exposure to organic chemicals in life cycle assessment: a new framework based on measured concentrations and labor hours. *Environmental Science & Technology* 49(14), 8741-8750. https://doi.org/10.1021/acs.est.5b00078.

Meesters, J.A., Koelmans, A.A., Quik, J.T., Hendriks, A.J. and van de Meent, D. (2014). Multimedia modeling of engineered nanoparticles with SimpleBox4nano: model definition and evaluation. *Environmental Science & Technology* 48(10). https://www.ncbi.nlm.nih.gov/pubmed/24766433.

Netherlands National Institute for Public Health and the Environment (2018). ConsExpo, 20 November. https://www.rivm.nl/en/Topics/C/ConsExpo. Accessed 30 December 2018.

Nordic Council of Ministers (2006). *Scoping Study on Releases from Products with a Proposal of the Next Steps*. https:/dx./doi.org/10.6027/tn2006-597.

Organisation for Economic Co-operation and Development (2008). *Complementing Guideline for Writing Emission Scenario Documents: The Life-cycle Step "Service-Life"*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2008)41/rev1&doclanguage=en.

Organisation for Economic Co-operation and Development (2012). *Description of Existing Models and Tools Used for Exposure Assessment: Results of OECD Survey*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/JM/MONO(2012)37&doclanguage=en.

Organisation for Economic Co-operation and Development (2013). *Guidance Document for Exposure Assessment Based on Environmental Monitoring*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2013)7&doclanguage=en.

Organisation for Economic Co-operation and Development (2017). *Resource Compendium of PRTR Release Estimation Techniques, Part 4: Summary of Techniques for Releases from Products*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2017)2/ann&doclanguage=en.

Organisation for Economic Co-operation and Development (2018a). Publications in the series on pollutant release and transfer registers. http://www.oecd.org/chemicalsafety/pollutant-release-transfer-register/publicationsintheseriesonpollutantreleaseandtransferregisters.htm. Accessed 31 May 2018.

Organisation for Economic Co-operation and Development (2018b). Introduction to emission scenario documents. http://www.oecd.org/env/ehs/risk-assessment/introductiontoemissionscenariodocuments.htm. Accessed 31 May 2018.

Organisation for Economic Co-operation and Development (2018c). OECD Pov and LRTP screening tool. http://www.oecd.org/env/ehs/risk-assessment/oecdpovandlrtpscreeningtool.htm. Accessed 31 May 2018.

Overcash, M. (2016). Environmental genome of industrial products (EGIP): the missing link for human health. *Green Chemistry* 18(12), 3600-3606. https://doi.org/10.1039/C6GC00182C.

Pharos (2018). Pharos Project. https://www.pharosproject.net/. Accessed 5 June 2018.

Posthuma, L., Dyer, S.D., de Zwart, D., Kapo, K., Holmes, C.M. and Burton, G.A. (2016). Eco-epidemiology of aquatic ecosystems: separating chemicals from multiple stressors. *Science of The Total Environment* 573, 1303-1319. https://doi.org/10.1016/J.SCITOTENV.2016.06.242.

Ring, C.L., Arnot, J., Bennett, D.H., Egeghy, P.P., Fantke, P., Huang, L., Isaacs, K.K., Jolliet, O., Phillips, K.A., Price, P.S., Shin, H.M., Westgate, J.N., W, S.R. and F, W.J. (2018). Chemical exposure pathway prediction for screening and priority-setting. *Submitted to Environmental Science & Technology*.

Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, M.A.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., van de Meent, D. and Hauschild, M.Z. (2008). USEtox – the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. *The International Journal of Life Cycle Assessment* 13(7), 532-546. https://doi.org/10.1007/s11367-008-0038-4.

Rosenbaum, R.K., Huijbregts, M.A.J., Henderson, A.D., Margni, M., McKone, T.E., van de Meent, D., Hauschild, M.Z., Shaked, S., Li, D.S., Gold, L.S. and Jolliet, O. (2011). USEtox human exposure and toxicity factors for comparative assessment of toxic emissions in life cycle analysis: sensitivity to key chemical properties. *The International Journal of Life Cycle Assessment* 16(8), 710-727. https://doi.org/10.1007/s11367-011-0316-4.

Scanlon, K.A., Lloyd, S.M., Gray, G.M., Francis, R.A. and LaPuma, P. (2015). An approach to integrating occupational safety and health into life cycle assessment: development and application of work environment characterization factors. *Journal of Industrial Ecology* 19(1), 27-37. https://doi.org/10.1111/jiec.12146.

Secretariat of the Convention on Biological Diversity (2010). *Global Biodiversity Outlook 3*. https://www.cbd.int/doc/publications/gbo/gbo3-final-en.pdf.

Shin, H.-M., Ernstoff, A., Arnot, J.A., Wetmore, B.A., Csiszar, S.A., Fantke, P., Zhang, X., McKone, T.E., Jolliet, O. and Bennett, D.H. (2015). Risk-based high-throughput chemical screening and prioritization using exposure models and in vitro bioactivity assays. *Environmental Science & Technology* 49(11), 6760-6771. https://doi.org/10.1021/acs.est.5b00498.

United Nations Economic Commission for Europe (2018). Introduction: Kyiv Protocol on Pollutant Release and Transfer Registers. https://www.unece.org/env/pp/prtr.html. Accessed 30 December 2018.

United Nations Environment Programme (2017). *Towards a Pollution-free Planet: Background Report*. https://wedocs.unep.org/bitstream/handle/20.500.11822/21800/UNEA_towardspollution_long%20version_Web.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme and World Health Organization (2013) *Results of the Global Survey on Concentrations in Human Milk of Persistent Organic Pollutants by the United Nations Environment Programme and the World Health Organization.* Geneva: Secretariat of the Stockholm Convention. http://wedocs.unep.org/bitstream/handle/20.500.11822/19392/UNEPPOPSCOP6INF33English_%281%29.pdf?sequence=1&isAllowed=y.

United Nations Institute for Training and Research (2018). UNITAR PRTR Platform. http://prtr.unitar.org/site/resources. Accessed 31 May 2018.

United States Centers for Disease Control and Prevention (2018a). National health and nutrition examination survey. https://www.cdc.gov/nchs/nhanes/index.htm. Accessed 1 June 2018.

United States Centers for Disease Control and Prevention (2018b). National Report on Human Exposure to Environmental Chemicals, March. https://www.cdc.gov/exposurereport/index.html. Accessed 17 August 2018.

United States Environmental Protection Agency (2016) ChemSTEER-chemical screening tool for exposures and environmental releases, 7 September. https://www.epa.gov/tsca-screening-tools/chemsteer-chemical-screening-tool-exposures-and-environmental-releases. Accessed 30 December 2018.

United States Environmental Protection Agency (2017a). Assessing human health risk from pesticides, 31 August. https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/assessing-human-health-risk-pesticides. Accessed 3 June 2018.

United States Environmental Protection Agency (2017b). Predictive models and tools for assessing chemicals under the Toxic Substances Control Act (TSCA), 18 December. https://www.epa.gov/tsca-screening-tools. Accessed 30 December 2018.

United States Environmental Protection Agency (2017c). Environmental measurements and modeling: collection of methods, 3 October. https://www.epa.gov/measurements-modeling/collection-methods. Accessed 1 June 2018.

United States Environmental Protection Agency (2017d). Exposure assessment tools by tiers and types: aggregate and cumulative, 29 November. https://www.epa.gov/expobox/exposure-assessment-tools-tiers-and-types-aggregate-and-cumulative. Accessed 3 June 2018.

United States Environmental Protection Agency (2017e). Exposure assessment tools by chemical classes, 1 December. https://www.epa.gov/expobox/exposure-assessment-tools-chemical-classes. Accessed 1 June 2018.

United States Environmental Protecrtion Agency (2018). Rapid chemical exposure and dose research, 9 October. https://www.epa.gov/chemical-research/rapid-chemical-exposure-and-dose-research. Accessed 30 December 2018.

van de Meent, D. and de Bruijn, J.H.M. (2007). Environmental exposure assessment. In *Risk assessment of chemicals: An introduction*. 2nd edn. van Leeuwen, C.J. and Vermeire, T. (eds). Dordrecht: Springer. Chapter 4. 159-194. https://www.springer.com/gp/book/9781402061011.

Wambaugh, J.F., Setzer, R.W., Reif, D.M., Gangwal, S., Mitchell-Blackwood, J., Arnot, J.A., Joliet, O., Frame, A., Rabinowitz, J., Knudsen, T.B., Judson, R.S., Egeghy, P., Vallero, D. and Cohen Hubal, E.A. (2013). High-throughput models for exposure-based chemical prioritization in the ExpoCast project. *Environmental Science & Technology* 47(15), 8479-8488. https://doi.org/10.1021/es400482g.

Wannaz, C., Franco, A., Kilgallon, J., Hodges, J. and Jolliet, O. (2018). A global framework to model spatial ecosystems exposure to home and personal care chemicals in Asia. *Science of The Total Environment* 622-623, 410-420. https://doi.org/10.1016/j.scitotenv.2017.11.315.

World Health Organization (2004). *IPCS Harmonization Project – IPCS Risk Assessment Terminology*. http://www.inchem.org/documents/harmproj/harmproj/harmproj1.pdf.

## Chapter 3

Ågerstrand, M. and Beronius, A. (2016). Weight of evidence evaluation and systematic review in EU chemical risk assessment: foundation is laid but guidance is needed. *Environment International* 92-93, 590-596. https://doi.org/10.1016/j.envint.2015.10.008.

American Chemistry Council (2018). Another milestone for the succesful implementation of TSCA, 17 August. https://blog.americanchemistry.com/2018/08/another-milestone-for-the-successful-implementation-of-tsca/. Accessed 4 January 2019.

Backhaus, T. (2015). *An Additional Assessment Factor (MAF) – A Suitable Approach for Improving the Regulatory Risk Assessment of Chemical Mixtures?* Stockholm: Swedish Chemicals Agency. https://www.kemi.se/global/rapporter/2015/rapport-5-15.pdf.

Backhaus, T., Scheringer, M. and Wang, Z. (2018). Developing SAICM into a framework for the international governance of chemicals throughout their lifecycle: Looking beyond 2020. In *Integrated Environmental Assessment and Management*. Wiley-VCH Verlag GmbH & Co. KGaA. https://doi.org/10.1002/3527607463.

Brown, A.R., Whale, G., Jackson, M., Marshall, S., Hamer, M., Solga, A., Kabouw, P., Galay-Burgos, M., Woods, R., Nadzialek, S. and Maltby, L. (2017). Toward the definition of specific protection goals for the environmental risk assessment of chemicals: a perspective on environmental regulation in Europe. *Integrated Environmental Assessment and Management* 13(1), 17-37. https://doi.org/10.1002/ieam.1797.

Carusi, A., Davies, M.R., De Grandis, G., Escher, B.I., Hodges, G., Leung, K.M.Y., Whelan, M., Willett, C. and Ankley, G.T. (2018). Harvesting the promise of AOPs: an assessment and recommendations. *Science of The Total Environment* 628-629, 1542-1556. https://doi.org/10.1016/J.SCITOTENV.2018.02.015.

Chiu, W.A. (2017). *Chemical Risk Assessment and Translation to Socio-economic Assessments*. Paris: Organisation for Economic Co-operation and Development. http://dx.doi.org/10.1787/a930054b-en.

Environment and Climate Change Canada (2016). *Chemicals Management Plan (CMP) Science Committee Objectives Paper: Meeting No. 5; 16-17 November 2016. Integrating New Approach Methodologies within the CMP: Identifying Priorities for Risk Assessment, Existing Substances Risk Assessment Program*. http://www.ec.gc.ca/ese-ees/172614CE-D9F6-43DA-A528-B8175438210F/Objectives%20Paper%20November%202016_EN.pdf.

Environment and Climate Change Canada and Health Canada (2017). Draft screening assessment substances identified as being of low concern using the ecological risk classification of organic substances and the threshold of toxicological concern (TTC)-based approach for certain substances, June. http://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=8A598C49-1. Accessed 4 January 2019.

Escher, B.I., Hackermüller, J., Polte, T., Scholz, S., Aigner, A., Altenburger, R., Böhme, A., Bopp, S.K., Brack, W., Busch, W., Chadeau-Hyam, M., Covaci, A., Eisenträger, A., Galligan, J.J., Garcia-Reyero, N., Hartung, T., Hein, M., Herberth, G., Jahnke, A., Kleinjans, J., Klüver, N., Krauss, M., Lamoree, M., Lehmann, I., Luckenbach, T., Miller, G.W., Müller, A., Phillips, D.H., Reemtsma, T., Rolle-Kampczyk, U., Schüürmann, G., Schwikowski, B., Tan, Y.-M., Trump, S., Walter-Rohde, S. and Wambaugh, J.F. (2017). From the exposome to mechanistic understanding of chemical-induced adverse effects. *Environment International* 99, 97-106. https://doi.org/10.1016/J.ENVINT.2016.11.029.

European Chemicals Agency (2017) *Non-animal Approaches - Current Status of Regulatory Applicability Under the REACH, CLP and Biocidal Products Regulations* https://echa.europa.eu/documents/10162/22931011/non_animal_approcches_en.pdf/87ebb68f-2038-f597-fc33-f4003e9e7d7d.

European Chemicals Agency (n.d. a). Search for chemicals. https://www.echa.europa.eu/information-on-chemicals. Accessed 30 December 2018.

European Chemicals Agency (n.d. b). How to avoid unnecessary testing on animals: weight of evidence. https://echa.europa.eu/support/registration/how-to-avoid-unnecessary-testing-on-animals/weight-of-evidence. Accessed 4 January 2019.

European Chemicals Agency (n.d. c). How to avoid unnecessary testing on animals: grouping of substances and read-across. https://echa.europa.eu/support/registration/how-to-avoid-unnecessary-testing-on-animals/grouping-of-substances-and-read-across. Accessed 29 August 2018.

European Commission (2015). Exposing the exposome, 22 September. *Horizon 2020*. https://ec.europa.eu/programmes/horizon2020/en/news/exposing-exposome. Accessed 1 January 2019.

European Commission (2018a). Nanomaterials in REACH and CLP. http://ec.europa.eu/environment/chemicals/nanotech/reach-clp/index_en.htm. Accessed 23 August 2018.

European Commission (2018b). *Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee: General Report on the Operation of REACH and Review of Certain Elements. Conclusions and Actions.* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0116&from=EN.

European Commission (2018c). The REACH REFIT evaluation (REACH review). https://ec.europa.eu/growth/sectors/chemicals/reach/review_en. Accessed 29 August 2018.

European Commission (2018d). Information platform for chemical monitoring: enhancing access to chemical data. Environmental Sciences Europe. https://ipchem.jrc.ec.europa.eu. Accessed 30 December 2018.

European Food Safety Authority (2010). Scientific Opinion on the development of specific protection goal options for environmental risk assessment of pesticides, in particular in relation to the revision of the guidance documents on aquatic and terrestrial ecotoxicology (SANCO/3268/2001 and SANCO/10329/2002. *European Food Safety Authority Journal* 8(10), 1821-1876. https://doi.org/10.2903/j.efsa.2010.1821.

European Food Safety Authority (2012). Scientific Opinion on exploring options for providing advice about possible human health risks based on the concept of threshold of toxicological concern (TTC). *European Food Safety Authority Journal* 10(7), 2750-2853. https://doi.org/10.2903/j.efsa.2012.2750.

European Food Safety Authority (2016). Guidance to develop specific protection goals options for environmental risk assessment at EFSA, in relation to biodiversity and ecosystem services. *European Food Safety Authority Journal* 14(6), 4499-4549. https://doi.org/10.2903/j.efsa.2016.4499.

European Food Safety Authority (n.d.). Chemical mixtures. https://www.efsa.europa.eu/en/topics/topic/chemical-mixtures. Accessed 29 August 2018.

Finkel, A.M. (2011). "Solution-focused risk assessment": a proposal for the fusion of environmental analysis and action. *Human and Ecological Risk Assessment: An International Journal* 17(4), 754-787. https://doi.org/10.1080/10807039.2011.588142.

Food and Agriculture Organization of the United Nations (2011). *One Health: Food and Agriculture Organization of the United Nations Strategic Plan*. http://www.fao.org/docrep/014/al868e/al868e00.pdf.

Franklin, K. (2018). EPA lays out TSCA implementation priorities, 1 November. https://chemicalwatch.com/71532/epa-lays-out-tsca-implementation-priorities. Accessed 4 January 2019.

Gottardo, S., Alessandrelli, M., Amenta, V., Atluri, R., Barberio, G., Bekker, C., Bergonzo, P., Bleeker, E., Booth, A.M., Borges, T., Buttol, P., Carlander, D., Castelli, S., Chevillard, S., Clavaguera, S., Dekkers, S., Delpivo, C., Di Prospero Fanghella, P., Dusinska, M., Einola, J., Ekokoski, E., Fito, C., Gouveia, H., Grall, R., Hoehener, K. and Joh, H. (2017). *NANoREG Framework for the Safety Assessment of Nanomaterials.* Gottardo, S., Crutzen, H. and Jantunen, P. (eds.). Ispra: Joint Research Centre. https://doi.org/10.2760/245972.

Government of Canada (2016a). Chemicals management plan, 2 June. https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan.html. Accessed 1 January 2019.

Government of Canada (2016b). Chemicals management plan risk assessment toolbox, 30 May. https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/chemicals-management-plan-risk-assessment-toolbox.html. Accessed 1 January 2019.

Government of Canada (2017a). The identification of risk assessment priorities, 15 June. https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/identification-risk-assessment-priorities.html. Accessed 4 Janaury 2019.

Government of Canada (2017b). Application of weight of evidence and precaution in risk assessment, 15 June. https://www.canada.ca/en/health-canada/services/chemical-substances/fact-sheets/application-weight-of-evidence-precaution-risk-assessments.html. Accessed 4 January 2019.

Government of Canada (2018a). *Chemicals Management Plan Progress Report: Summer 2018*. https://www.canada.ca/content/dam/eccc/documents/pdf/pded/chemicals-management-plan-(cmp)-progress-report/cmp-progress-report-summer-2018.pdf.

Government of Canada (2018b). *Follow-Up Report to the House of Commons Standing Committee on Environment and Sustainable Development on the Canadian Environmental Protection Act, 1999*. Ottawa. https://www.canada.ca/content/dam/eccc/documents/pdf/cepa/FollowUpCepaReport-eng.pdf

Hansen, B.G. (2017). Hazard versus risk, Chemical Watch, October. https://chemicalwatch.com/60340/hazard-versus-risk. Accessed 1 June 2018

Human Exposome Project (2019) The exposome's 10th year in review https://humanexposomeproject.com/news/the-exposomes-10th-year-in-review/. Accessed 4 January 2019.

International Chemical Secretariat (n.d.). Sin list. http://chemsec.org/sin-list/. Accessed 1 June 2018.

Jabbour, J. and Flachsland, C. (2017). 40 years of global environmental assessments: a retrospective analysis. *Environmental Science & Policy* 77, 193-202. https://doi.org/10.1016/J.ENVSCI.2017.05.001.

Karmaus, A.L., Filer, D.L., Martin, M.T. and Houck, K.A. (2016). Evaluation of food-relevant chemicals in the ToxCast high-throughput screening program. *Food and Chemical Toxicology* 92, 188-196. https://doi.org/10.1016/j.fct.2016.04.012.

Kortenkamp, A., Backhaus, T. and Faust, M. (2009). *State of the Art Report on Mixture Toxicity: Final Report*. Executive Summary. European Commission, DG Environment. http://ec.europa.eu/environment/chemicals/effects/pdf/report_mixture_toxicity.pdf.

Laux, P., Tentschert, J., Riebeling, C., Braeuning, A., Creutzenberg, O., Epp, A., Fessard, V., Haas, K.-H., Haase, A., Hund-Rinke, K., Jakubowski, N., Kearns, P., Lampen, A., Rauscher, H., Schoonjans, R., Störmer, A., Thielmann, A., Mühle, U. and Luch, A. (2018). Nanomaterials: certain aspects of application, risk assessment and risk communication. *Archives of Technology* 92(1) 121-141. https://doi.org/10.1007/s00204-017-2144-1.

Liu, J., Patlewicz, G., Williams A.J., Thomas R.S., and Shah I. (2017). Predicting organ toxicity using *in vitro* bioactivity data and chemical structure. *Chemical Research in Toxicology* 30(11), 2046-2059. https://doi.org/10.1021/acs.chemrestox.7b00084.

Maltby, L., Jackson, M., Whale, G., Brown, A.R., Hamer, M., Solga, A., Kabouw, P., Woods, R. and Marshall, S. (2017). Is an ecosystem services-based approach developed for setting specific protection goals for plant protection products applicable to other chemicals? *Science of The Total Environment* 580, 1222-1236. https://doi.org/10.1016/J.SCITOTENV.2016.12.083.

Meek, B., Boobis, A.R., Crofton, K.M., Heinemeyer, G., Raaij, M. Van and Vickers, C. (2011). Risk assessment of combined exposure to multiple chemicals: a WHO/IPCS framework. *Regulatory Toxicology and Pharmacology* 60(2), S1-S14. https://doi.org/10.1016/j.yrtph.2011.03.010.

Milner, A.M. and Boyd, I.L. (2017). Toward pesticidovigilance. *Science* 357(6357), 1232-1234. https://doi.org/10.1126/science.aan2683.

Organisation for Economic Co-operation and Development (2002) *OECD Guidance Document on Risk Communication for Chemical Risk Management.* http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2002)18&doclanguage=en

Organisation for Economic Co-operation and Development (2011). *WHO OECD ILSI/HESI International Workshop on Risk Assessment of Combined Exposures to Multiple Chemicals.* Workshop Report. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2011)10&doclanguage=en.

Organisation for Economic Co-operation and Development (2014). *Guidance on Grouping of Chemicals*. 2nd edn. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2014)4&doclanguage=en.

Organisation for Economic Co-operation and Development (2016). OECD environmental risk assessment toolkit. https://envriskassessmenttoolkit.oecd.org/Default.aspx?idExec=c024b15b-9573-433c-a8a1-f100951a0686. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018). Grouping of chemicals: chemical categories and read-across. http://www.oecd.org/chemicalsafety/risk-assessment/groupingofchemicalschemicalcategoriesandread-across.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (n.d.). The global portal to information on chemical substances. *eChemPortal*. https://www.echemportal.org/echemportal/index.action. Accessed 1 January 2019.

Pham, N., Iyer, S., Hackett, E., Lock, B.H., Sandy, M., Zeise, L., Solomon, G. and Marty, M. (2016). Using ToxCast to explore chemical activities and hazard traits: a case study with ortho- phthalates. *Toxicological Sciences* 151(2), 286-301. https://doi.org/10.1093/toxsci/kfw049.

Pleil, J. (2015). The human exposome and systems biology: ongoing empirical measurement studies and biomarker interpretation, 57 May. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=311388&Lab=NERL. Accessed 3 January 2019.

Rhomberg, L.R., Goodman , J.E., Bailey , L.A., Prueitt, R.L., Beck, N.B., Bevan, C., Honeycutt, M., Kaminski, N.E., Paoli, G., Pottenger, L.H., Scherer, R.W., Wise, K.C. and Becker, R.A. (2013). A survey of frameworks for best practices in weight-of-evidence analyses. *Critical Reviews in Toxicology* 43(9), 753-784. https://doi.org/10.3109/10408444.2013.832727.

Roth, N. and Wilks, M.F. (2014). Neurodevelopmental and neurobehavioural effects of polybrominated and perfluorinated chemicals: a systematic review of the epidemiological literature using a quality assessment scheme. *Toxicology Letters* 230(2), 271-281. https://doi.org/10.1016/j.toxlet.2014.02.015.

Sahlin, U. and Rundlöf, M. (2016). Differences in the strengths of evidence matters in risk-risk trade-offs. *Journal of Risk Research* 20(8), 988-994. https://doi.org/10.1080/13669877.2016.1178662.

Selin, H. (2013). Global chemicals politics and policy. In *The Handbook of Global Climate and Environment Policy*. Oxford: Wiley. 107-123. https://doi.org/10.1002/9781118326213.ch7.

Shah, F. and Greene, N. (2014). Analysis of Pfizer compounds in EPA's ToxCast chemicals-assay space. *Chemical Research in Toxicology* 27(1), 86-98. https://doi.org/10.1021/tx400343t.

Swedish Chemicals Agency (2018). *Grouping of Chemical Substances in the REACH and CLP Regulations*. https://www.kemi.se/global/pm/2018/pm-2-18-grouping-of-chemical-substances-in-the-reach-and-clp-regulations1.pdf.

Teeguarden, J.G., Tan, Y.-M., Edwards, S.W., Leonard, J.A., Anderson, K.A., Corley, R.A., Kile, M.L., Simonich, S.M., Stone, D., Tanguay, R.L., Waters, K.M., Harper, S.L. and Williams, D.E. (2016). Completing the link between exposure science and toxicology for improved environmental health decision making: the aggregate exposure pathway framework. *Environmental Science & Technology* 50(9), 4579-4586. https://doi.org/10.1021/acs.est.5b05311.

United Nations (2017). *Globally Harmonized System of Classification and Labelling of Chemicals (GHS): Health and Environmental Hazards - Classification Criteria for Substances and Mixtures.* https://www.unece.org/fileadmin/DAM/trans/danger/publi/ghs/GHS_presentations/English/health_env_e.pdf.

United Nations Office for Disaster Risk Reduction (2017). *Words into Action Guidelines: National Disaster Risk Assessment. Special Topics A. Public Communication for Disaster Risk Reduction.* https://www.preventionweb.net/files/52828_apubliccommunication[1].pdf.

United States Agency for Toxic Substances and Disease Registry (2018) *Framework for Assessing Health Impacts of Multiple Chemicals and Other Stressors (Update).* https://www.atsdr.cdc.gov/interactionprofiles/ip-ga/ipga-p.pdf.

United States Centers for Disease Control and Prevention (2018). National Health and Nutrition Examination Survey. https://www.cdc.gov/nchs/nhanes/index.htm. Accessed 1 June 2018.

United States Congress (2016). *The Frank R. Lautenberg Chemical Safety for the 21st Century Act. Public Law 114-182 - 114th Congress*. https://www.congress.gov/114/plaws/publ182/PLAW-114publ182.pdf.

United States Environmental Protection Agency (2017). Control of nanoscale materials under the Toxic Substances Control Act, 30 November. https://www.epa.gov/reviewing-new-chemicals-under-toxic-substances-control-act-tsca/control-nanoscale-materials-under. Accessed 14 August 2018.

United States Environmental Protection Agency (2018a). Exploring ToxCast data: downloadable data. https://www.epa.gov/chemical-research/exploring-toxcast-data-downloadable-data. Accessed 1 January 2019.

United States Environmental Protection Agency (2018b). ChemView. https://chemview.epa.gov/chemview. Accessed 1 June 2018.

United States Environmental Protection Agency (2018c). CompTox chemicals dashboard: what is the comptox chemicals dashboard? 13 December. https://www.epa.gov/chemical-research/comptox-chemicals-dashboard. Accessed 1 January 2019.

United States Environmental Protection Agency (2018d). *Application of Systematic Review in TSCA Evaluations.* https://www.epa.gov/sites/production/files/2018-06/documents/final_application_of_sr_in_tsca_05-31-18.pdf.

United States National Academies of Sciences, Engineering and Medicine (2017). *Using 21st Century Science to Improve Risk-related Evaluations*. https://www.nap.edu/catalog/24635/using-21st-century-science-to-improve-risk-related-evaluations.

United States National Research Council (2009). *Science and Decision: Advancing Risk Assessment.* https://doi.org/10.17226/12209.

United States National Toxicology Program (2017). Collaborative workshop on aquatic models and 21st century toxicology, 12 December. https://ntp.niehs.nih.gov/pubhealth/evalatm/3rs-meetings/past-meetings/aquatic-models-wksp-2014/index.html. Accessed 1 January 2019.

United States National Toxicology Program (2018a). OHAT systematic review, 29 January. https://ntp.niehs.nih.gov/pubhealth/hat/review/index-2.html. Accessed 1 January 2019.

United States National Toxicology Program (2018b). SEAZIT: systematic evaluation of the application of zebrafish in toxicology, 30 August. https://ntp.niehs.nih.gov/pubhealth/evalatm/test-method-evaluations/dev-tox/seazit/index.html. Accessed 1 January 2019.

van Broekhuizen, F.A., Posthuma L. and Traas T.P. (2016). *Addressing Combined Effects of Chemicals in Environmental Safety Assessment Under REACH – A Thought Starter*. Bilthoven: Netherlands National Institute for Public Health and the Environment. https://www.rivm.nl/en/Documents_and_publications/Scientific/Reports/2017/February/Addressing_combined_effects_of_chemicals_in_environmental_safety_assessment_under_REACH_A_thought_starter.

van Wezel, A.P., Laak, T.L. ter, Fischer, A., Bäuerlein, P.S., Munthe, J. and Posthuma, L. (2017). Mitigation options for chemicals of emerging concern in surface waters; operationalising solutions-focused risk assessment. *Environmental Science: Water Research & Technology* 3(3), 403-414. https://doi.org/10.1039/C7EW00077D.

Wang, J.C., Zhao, N.N., Chen, Y. and Li, J.H. (2015). A comparative review on chemical registration management regulations. *Applied Mechanics and Materials* 768, 820-827. https://doi.org/10.4028/www.scientific.net/AMM.768.820.

Wignall, J.A., Muratov, E., Sedykh, A., Guyton, K.Z., Tropsha, A., Rusyn, I. and Chiu, W.A. (2018). Conditional toxicity value (CTV) predictor: an in silico approach for generating quantitative risk estimates for chemicals. *Environmental Health Perspectives* 126(5), 057008-1-13. https://doi.org/10.1289/EHP2998.

Wilks, M.F., Roth, N., Aicher, L., Faust, M., Papadaki, P., Marchis, A., Calliera, M., Ginebreda, A., Andres, S., Kühne, R., Schüürmann, G. and HEROIC consortium. (2015). White paper on the promotion of an integrated risk assessment concept in European regulatory frameworks for chemicals. *Science of The Total Environment* 521-522, 211-218. https://doi.org/10.1016/j.scitotenv.2015.03.065.

Williams, A.J., Grulke, C.M., Edwards, J., McEachran, A.D., Mansouri, K., Baker, N.C., Patlewicz, G., Shah, I., Wambaugh, J.F., Judson, R.S. and Richard, A.M. (2017). The CompTox chemistry dashboard: a community data resource for environmental chemistry. *Journal of Cheminformatics* 9(61), 1-27. https://doi.org/10.1186/s13321-017-0247-6.

Woodruff, T.J. and Sutton, P. (2014). The navigation guide systematic review methodology: a rigorous and transparent method for translating environmental health science into better health outcomes. *Environmental Health Perspectives* 122(10), 1007-1014. https://doi.org/10.1289/ehp.1307175.

World Health Organization (2010). *WHO Human Health Risk Assessment Toolkit: Chemical Hazards*. http://apps.who.int/iris/bitstream/handle/10665/44458/9789241548076_eng.pdf;jsessionid=13EE48B03B976863804FF725EE3AC471?sequence=1.

World Health Organization (2017a). *Chemical Mixtures in Source Water and Drinking-water*. http://apps.who.int/iris/bitstream/handle/10665/255543/9789241512374-eng.pdf;jsessionid=945450215FE5D872A33483300F7FD600?sequence=1.

World Health Organization (2017b). One health. http://www.who.int/features/qa/one-health/en/. Accessed 29 August 2018.

World Health Organization (2017c). *Guidance Document on Evaluating and Expressing Uncertenty in Hazard Characterization.* 2nd edn. http://apps.who.int/iris/bitstream/handle/10665/259858/9789241513548-eng.pdf;jsessionid=68396397355FA003FCBB5E3A8096AA2C?sequence=1.

World Health Organization (2018a). Integrated risk assessment. http://www.who.int/ipcs/methods/risk_assessment/en/. Accessed 1 June 2018.

World Health Organization (2018b). International programme on chemical safety: chemical risk assessment network. http://www.who.int/ipcs/network/en/. Accessed 1 June 2018.

World Organization for Animal Health (2018). One health "at a glance". http://www.oie.int/en/for-the-media/onehealth/. Accessed 29 August 2018.

## Chapter 4

Atkinson, G., Braathen, N.A., Groom, B. and Mourato, S. (2018). *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use.* Paris: Organisation for Economic Development and Co-operation. https://doi.org/10.1787/9789264085169-en.

Bartelings, H., Kavallari, A., van Meijl, H. and Von Lampe, M. (2016). *Estimating the Impact of Fertilizer Support Policies: A CGE approach.* Washington, D.C.: Global Trade Analysis Project. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=4901.

Bernstein, S. and Cashore, B. (2007). Can non-state global governance be legitimate? An analytical framework. *Regulation & Governance* 1(4), 347-371. https://doi.org/10.1111/j.1748-5991.2007.00021.x.

Berrone, P., Fosfuri, A., Gelabert, L. and Gomez-Mejia, L.R. (2013). Necessity as the mother of 'green' inventions: institutional pressures and environmental innovations. *Strategic Management Journal* 34(8), 891-909. https://doi.org/10.1002/smj.2041.

Böcker, T. and Finger, R. (2016). European pesticide tax schemes in comparison: an analysis of experiences and developments. *Sustainability* 8(4), 1-22. https://doi.org/10.3390/su8040378.

Boström, M., Börjeson, N., Gilek, M., Jönsson, A.M. and Karlsson, M. (2011). *Towards Responsible Procurement in Relation to Chemical Risks in Textiles? Findings from an Interview Study.* Huddinge: Södertörn University. https://pdfs.semanticscholar.org/f878/613c306f2c4e44bca438c8af423bedfdb3c0.pdf.

Botos, Á., Graham, J.D. and Illés, Z. (2018). Industrial chemical regulation in the European Union and the United States: a comparison of REACH and the amended TSCA. *Journal of Risk Research* 1-18. https://doi.org/10.1080/13669877.2018.1454495.

Buxton, L. (2016). Hoffmann-La Roche´s goal to phase out SVHCs, December. *Chemical Watch*. https://chemicalwatch.com/51621/hoffmann-la-roches-goal-to-phase-out-svhcs. Accessed 2 January 2019.

Canan, P., Andersen, S.O., Reichman, N. and Gareau, B. (2015). Introduction to the special issue on ozone layer protection and climate change: the extraordinary experience of building the Montreal Protocol, lessons learned, and hopes for future climate change efforts. *Journal of Environmental Studies and Sciences* 5(2), 111-121. https://doi.org/10.1007/s13412-015-0224-1.

Center for International Environmental Law (2013). *Driving Innovation: How Stronger Laws Help Bring Safer Chemicals to the Market*. http://www.ciel.org/Publications/Innovation_Chemical_Feb2013.pdf.

ChemSafetyPro (2018) GHS Classification of mixture, 17 October. https://www.chemsafetypro.com/Topics/GHS/GHS_classification_mixture.html. Accessed 2 January 2019.

Chiu, W.A. (2017). *Chemical Risk Assessment and Translation to Socio-economic Assessments*. Paris: Organisation for Economic Co-operation and Development. http://dx.doi.org/10.1787/a930054b-en.

Consultancy.uk (2017). Portfolio Sustainability Assessment gaining momentum in chemicals industry, 28 March. https://www.consultancy.uk/news/13241/portfolio-sustainability-assessment-gaining-momentum-in-chemicals-industry. Accessed 1 January 2019.

Cook, G. and Jardim, E. (2017). *Guide to Greener Electronics 2017*. Bach, N. (ed.). Washington, D.C.: Greenpeace. https://www.greenpeace.org/usa/wp-content/uploads/2017/10/Guide-to-Greener-Electronics-2017.pdf.

Dalvie, M.A., Rother, H.A. and London, L. (2014). Chemical hazard communication comprehensibility in South Africa: safety implications for the adoption of the globally harmonised system of classification and labelling of chemicals. *Safety Science* 61, 51-58. https://doi.org/10.1016/j.ssci.2013.07.013.

Duffus, J.H., Nordberg, M. and Templeton, D.M. (2007). Glossary of terms used in toxicology, 2nd edition (IUPAC Recommendations 2007). *Pure and Applied Chemistry. The Journal of the International Union of Pure and Applied Chemistry (IUPAC)* 79(7), 1153-1344. https://doi.org/10.1351/pac200779071153.

DuPont (2015). DuPont position statement: Montreal Protocol, 15 September. http://www.dupont.com/corporate-functions/our-company/insights/articles/position-statements/articles/montreal-protocol.html. Accessed 1 June 2018.

Eastlake, A., Hodson, L., Geraci, C. and Crawford, C. (2012). A critical evaluation of material safety data sheets (MSDSs) for engineered nanomaterials. *Chemical Health & Safety* 19(5), 1-8. https://doi.org/10.1016/j.jchas.2012.02.002.

Egeghy, P.P., Judson, R., Gangwal, S., Mosher, S., Smith, D., Vail, J. and Cohen Hubal, E.A. (2012). The exposure data landscape for manufactured chemicals. *Science of The Total Environment* 414, 159-166. https://doi.org/10.1016/j.scitotenv.2011.10.046.

Egeghy, P.P., Vallero, D.A. and Cohen Hubal, E.A. (2011). Exposure-based prioritization of chemicals for risk assessment. *Environmental Science & Policy* 14(8), 950-964. https://doi.org/10.1016/J.ENVSCI.2011.07.010.

Eklund, A.G., Altshuler, S.L., Altshuler, P.C., Chow, J.C., Hidy, G.M., Lloyd, A.C., Prather, M.J., Watson, J.G., Zalzal, P., Andersen, S.O., Halberstadt, M.L. and Borgford-Parnell, N. (2013). Stratospheric ozone, global warming, and the principle of unintended consequences – an ongoing science and policy story. *Journal of the Air & Waste Management Association* 63(11), 1235-1244. https://doi.org/10.1080/10962247.2013.847317.

European Chemicals Agency (2011). *Guidance on the Preparation of an Application for Authorisation*. Version 1. https://echa.europa.eu/documents/10162/13643/authorisation_application_en.pdf.

European Chemicals Agency (2017). *Socio-economic Impacts of REACH Authorisations: A Meta-Analysis of the First 100 Applications for Authorisation*. https://doi.org/10.2823/794664.

European Chemicals Agency (n.d. a). Emission scenario documents. https://echa.europa.eu/guidance-documents/guidance-on-biocides-legislation/emission-scenario-documents. Accessed 23 August 2018.

European Chemicals Agency (n.d. b). Extended safety data sheets. https://echa.europa.eu/safety-data-sheets. Accessed 9 September 2018.

European Chemicals Agency (n.d. c) Classification of substances and mixtures https://echa.europa.eu/regulations/clp/classification. Accessed 2 January 2019.

European Chemicals Agency (n.d. d). Understanding REACH. https://echa.europa.eu/regulations/reach/understanding-reach. Accessed 1 June 2018.

European Chemicals Agency (n.d. e). Regulatory management option analysis. https://echa.europa.eu/rmoa. Accessed 1 June 2018.

European Commission (2015). *Monitoring the Impacts of REACH on Innovation, Competitiveness and SMEs*. http://ec.europa.eu/DocsRoom/documents/14581/attachments/1/translations.

Frangos, J., D'Costa, G., Hagen, T. and Drew, R. (2010). *An Evaluation of MSDS and Labels Associated with the Use of Engineered Nanomaterials.* Canberra: Safe Work Australia. https://www.safeworkaustralia.gov.au/system/files/documents/1702/anevaluationofmsdsandlabelsassociatedwiththeuseofengineerednanomaterials.doc.

Franklin, K. (2015). Trend in retailers removing phthalates from flooring continues, 16 July. *Chemical Watch*. https://chemicalwatch.com/24489/trend-in-retailers-removing-phthalates-from-flooring-continues. Accessed 1 June 2018.

Franklin, K. (2016). Walmart releases high priority chemical list: substances include formaldehyde, parabens, triclosan, NPEs, phthalates, 21 July. *Chemical Watch*. https://chemicalwatch.com/48724/walmart-releases-high-priority-chemical-list. Accessed 9 September 2018.

Gauthier, A.M., Fung, M., Panko, J., Kingsbury, T., Perez, A.L., Hitchcock, K., Ferracini, T., Sahmel, J., Banducci, A., Jacobsen, M., Abelmann, A. and Shay, E. (2014). Chemical assessment state of the science: evaluation of 32 decision-support tools used to screen and prioritize chemicals. *Integrated Environmental Assessment and Management* 11(2), 242-255. https://doi.org/10.1002/ieam.1605.

Geiser, K. (2015) *Chemicals Without Harm: Policies for a Sustainable World.* Cambridge, MA: MIT Press. http://mitpress.universitypressscholarship.com/view/10.7551/mitpress/9780262012522.001.0001/upso-9780262012522.

Government of Canada (2012). Chemicals Management Plan implementation table at a glance – 2016 to 2021, 26 July. https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan/implementation-table-at-a-glance-2016-2021.html. Accessed 22 August 2018.

Government of Canada (2016). Risk management of chemical substances: what is risk management? 4 July. https://www.canada.ca/en/health-canada/services/chemical-substances/canada-approach-chemicals/risk-management.html. Accessed 22 August 2018.

GreenBiz (2018). The right chemistry. https://www.greenbiz.com/blogs/enterprise/right-chemistry. Accessed 1 January 2019.

Green Chemistry and Commerce Council (n.d.). Advancing Green Chemistry across sectors and supply chains. https://www.greenchemistryandcommerce.org/. Accessed 2 January 2019.

Green Science Policy Institute (2013). Pop Stop: Denmark retailer stops sale of microwave popcorn amid health fears, 3 June. http://greensciencepolicy.org/pop-stop/. Accessed 1 June 2018.

GreenScreen (2018) GreenScreen for safer chemicals. https://www.greenscreenchemicals.org/. Accessed 9 September 2018.

Hansen, B.G. (2017). Hazard versus risk: the difference between alternative ways of managing chemicals is actually not that large, October. *Chemical Watch*. https://chemicalwatch.com/60340/hazard-versus-risk. Accessed 1 January 2019.

Hansson, S.O. (1997). Can we reverse the burden of proof? *Toxicology Letters* 90(2-3), 223-228. https://doi.org/10.1016/S0378-4274(96)03851-9.

Hartmann, S. and Klaschka, U. (2017). Interested consumers' awareness of harmful chemicals in everyday products. *Environmental sciences Europe* 29(1), 29. https://doi.org/10.1186/s12302-017-0127-8.

Henson, S. and Humphrey, J. (2009). *The Impacts of Private Food Safety Standards on the Food Chain and on Public Standard-setting Processes*. Rome and Geneva: Food and Agriculture Organization of the United Nations and World Health Organization. http://www.fao.org/3/a-i1132e.pdf.

Humphrey, J. (2017). Regulation, standards and risk management in the context of globalization. In *Regulations and International Trade: New Sustainability Challenges for East Asia.* 21-58. Michida, E., Humphrey J. and Nabeshima K. (eds.). Cham: Palgrave Macmillan. Chapter 2. 21-58. https://doi.org/10.1007/978-3-319-55041-1_2.

International Agency for Research on Cancer (2018). Agents classified by the IARC monographs. Volumes 1-121. https://monographs.iarc.fr/ENG/Classification/ClassificationsAlphaOrder.pdf.

International Chemical Trade Association (n.d.). Responsible care. https://www.icta-chem.org/explore-topics/responsible-care. Accessed 1 January 2019.

International Council of Chemical Associations (2015). Responsible Care® - the quest for performance excellence. https://www.icca-chem.org/responsible-care/. Accessed 22 August 2018.

International Finance Corporation (2012). *2012 Performance Standards*. https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/policies-standards/performance-standards.

International Labour Organization (2017). C170 - Chemicals Convention, 1990 (No. 170). Convention concerning Safety in the use of Chemicals at Work. https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C170. Accessed 23 August 2018.

International Labour Organization (2018). International chemical safety cards. https://www.ilo.org/safework/info/publications/WCMS_113134/lang--en/index.htm. Accessed 23 August 2018.

Jacobs, M.M., Malloy, T.F., Tickner, J.A. and Edwards, S. (2015). Alternatives assessment frameworks: research needs for the informed substitution of hazardous chemicals. *Environmental Health Perspectives* 124(3), 265-280. https://doi.org/10.1289/ehp.1409581.

Lee, J.H., Kuk, W.K., Kwon, M., Lee, J.H., Lee, K.S. and Yu, I.J. (2012). Evaluation of information in nanomaterial safety data sheets and development of international standard for guidance on preparation of nanomaterial safety data sheets. *Nanotoxicology* 7(3), 338-345. https://doi.org/10.3109/17435390.2012.658095.

Lofstedt, R.E. (2011). Risk versus hazard – how to regulate in the 21st century. *European Journal of Risk Regulation* (2), 149-168. http://risksummit.eu/wp-content/uploads/2013/06/Risk-Versus-Hazard-Prof.-Ragnar-Lofsted.pdf.

Massey, R. (2008). Sharing knowledge about chemicals: policy options for facilitating information flow. In *Options for State Chemicals Policy Reform – A Resource Guide.* Coffin, M. and Dunn, M.L. (eds.). Lowell, MA: Lowell Center for Sustainable Production. Chapter 2. 69–96. http://sustainableproduction.org/downloads/OptionsforStateChemicalsPolicyReform.pdf.

Maxwell, J. and Briscoe, F. (1997). There's money in the air: the CFC ban and DuPont's regulatory strategy. *Business Strategy and the Environment* 6(5), 276-286. https://doi.org/10.1002/(SICI)1099-0836(199711)6:5<276::AID-BSE123>3.0.CO;2-A.

Milieu, T.M.C. Asser Institute and PACE (2011). *Considerations on the Application of the Precautionary Principle in the Chemicals Sector: Final Report*. Brussels: European Commission. http://ec.europa.eu/environment/chemicals/reach/pdf/publications/final_report_pp.pdf.

Morita, T. and Morikawa, K. (2011). Expert review for GHS classification of chemicals on health effects. *Industrial Health* 49(5), 559-565. https://doi.org/10.2486/indhealth.MS1267.

Nicol, A.-M., Hurrell, A.C., Wahyuni, D., McDowall, W. and Chu, W. (2008). Accuracy, comprehensibility, and use of material safety data sheets: a review. *American Journal of Industrial Medicine* 51(11), 861-876. https://doi.org/10.1002/ajim.20613.

Organisation for Economic Co-operation and Development (2015). *Preliminary Analysis of Policy Drivers Influencing Decision Making in Chemicals Management*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2015)21&doclanguage=en.

Organisation for Economic Co-operation and Development (2016). *Workshop Report: OECD Workshop Report on Socioeconomic Impact Assessment of Chemicals Management*. https://echa.europa.eu/documents/10162/22816069/sea_oecd_workshop_chem_man_en.pdf/4c94f130-f04b-2c3f-ebda-55c2df236e97.

Organisation for Economic Co-operation and Development (2018a). Emission scenario documents. http://www.oecd.org/chemicalsafety/risk-assessment/emissionscenariodocuments.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018b). The costs and benefits of regulating chemicals. http://www.oecd.org/chemicalsafety/risk-management/sacame.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (2018c). IOMC toolbox for decision making in chemicals management, 25 May. https://iomctoolbox.oecd.org/Default.aspx?idExec=d39e45a0-70e0-47f4-9949-1ec46f320b1b. Accessed 1 June 2018.

Organisation for Economic Co-operation and Development (n.d.). Regulations and restrictions. http://www.oecdsaatoolbox.org/Home/Regulations. Accessed 1 January 2019.

Panko, J., Hitchcock, K., Fung, M., Spencer, P., Kingsbury, T. and Mason, A. (2017). A comparative evaluation of five hazard screening tools. *Integrated Environmental Assessment and Management*. 13(1), 139-154. https://doi.org/10.1002/ieam.1757.

Pedersen, A.B., (2016) *Pesticide Tax in Denmark*. Aarhus University and Institute for European Environmental Policy. https://ieep.eu/uploads/articles/attachments/504788d7-db01-4dd8-bece-ee7b9e63979e/DK%20Pesticide%20Tax%20final.pdf?v=63680923242.

Pelkmans, J. and Renda, A. (2014). *Does EU Regulation Hinder or Stimulate Innovation?* Brussels: Centre for European Policy Studies. https://www.ceps.eu/system/files/No%2096%20EU%20Legislation%20and%20Innovation.pdf.

Perlmutter, A. (2015a). *Advancing Safer Chemicals in Products: The Key Role of Purchasing*. Lowell, MA: University of Massachusetts Lowell. https://www.epa.gov/sites/production/files/2015-09/documents/uml-rpt_greenpurchasing_7_15_14-2_0.pdf.

Perlmutter, A. (2015b). The rise of the non-toxic buyer: 6 case studies on safer chemistry, 12 November. *GreenBiz*. https://www.greenbiz.com/article/rise-non-toxic-buyer-6-case-studies-safer-chemistry. Accessed 1 January 2019.

Persson, L., Karlsson-Vinkhuyzen, S., Lai, A., Persson, Å. and Fick, S. (2017). The globally harmonized system of classification and labelling of chemicals: explaining the legal implementation gap. *Sustainability* 9(12), 2176. https://doi.org/10.3390/su9122176.

Rossi, M.S., Edwards, S., Peele, C. and Greiner, T. (2017). *The Chemical Footprint Project: 2017 Annual Report*. Chemical Footprint Project. https://www.chemicalfootprint.org/info/cfp-report-2017.

Rother, H.-A. (2014). Communicating pesticide neurotoxicity research findings and risks to decision-makers and the public. *NeuroToxicology* 45, 327-337. https://doi.org/10.1016/j.neuro.2014.03.001.

Rother, H.-A. (2018). Pesticide labels: protecting liability or health? – unpacking 'misuse' of pesticides. *Current Opinion in Environmental Science & Health* 4, 10-15. https://doi.org/10.1016/j.coesh.2018.02.004.

Rotman, D. (2007). Remembering the Montreal Protocol, 1 January. *MIT Technology Review*. https://www.technologyreview.com/s/407083/remembering-the-montreal-protocol/. Accessed 2 June 2018.

Sathar, F., Dalvie, M. and Rother, H.-A. (2016). Review of the literature on determinants of chemical hazard information recall among workers and consumers. *International Journal of Environmental Research and Public Health* 13(6), 546. https://doi.org/10.3390/ijerph13060546.

Scott, J., Smith, T., Rehmatulla, N. and Milligan, B. (2017). The promise and limits of private standards in reducing greenhouse gas emissions from shipping. *Journal of Environmental Law*. 29(2), 231-262. https://doi.org/10.1093/jel/eqw033.

Stockholm Environment Institute (2014). *How Far to the 2020 goal? The Strategic Approach to International Chemicals Management in Tanzania*. https://www.sei.org/mediamanager/documents/Publications/SEI-PolicyBrief-Persson-Tanzania.pdf.

Stockholm Environment Institute (2017). *Reducing Chemical Risks in Low-income Countries: Strategies for Improved Coverage of Basic Chemicals-Management Legislation*. https://f88973py3n24eoxbq1o3o0fz-wpengine.netdna-ssl.com/wp-content/uploads/2018/03/180307c-brandon-persson-chemicals-pb-1802g.pdf.

Stringer, L. (2018). Cross-sector initiative sets full materials disclosure goal, 14 June. *Chemical Watch*. https://chemicalwatch.com/67695/cross-sector-initiative-sets-full-materials-disclosure-goal. Accessed 1 January 2019.

Ta, G.C., Mokhtar, M. Bin, Mohd Mokhtar, H.A. Bin, Ismail, A. Bin and Abu Yazid, M.F.B.H. (2010). Analysis of the comprehensibility of chemical hazard communication tools at the industrial workplace. *Industrial Health* 48(6), 835-844. https://doi.org/10.2486/indhealth.MS1153.

Tan, S.S. (2005). Decreasing environmental pollution through reducing environmentally damaging subsidies: the case of agricultural input subsidies. *Journal of Administrative Science* 3(2), 207-214. http://ybd.dergi.comu.edu.tr/dosyalar/Ybd/decreasing-environmental-pollution-through-reducing-environmentally-damagin-2017-02-13-212.pdf.

United Nations (1992). *Report of the United Nations Conference on Environment and Development - Annex 1: Rio Declaration on Environment and Development*. 14 June. A/CONF.151/26 (Vol. I). https://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm. Accessed 1 January 2019.

United Nations Economic Commission for Europe (2017). GHS presentations: Globally Harmonized System of Classification and Labelling of Chemicals (GHS). https://www.unece.org/trans/danger/publi/ghs/presentation_e.html. Accessed 1 January 2019.

United Nations Economic Commission for Europe (n.d. a). GHS implementation. https://www.unece.org/trans/danger/publi/ghs/implementation_e.html. Accessed 1 January 2019.

United Nations Economic Commission for Europe (n.d. b). GHS pictograms. https://www.unece.org/trans/danger/publi/ghs/pictograms.html. Accessed 2 June 2018.

United Nations Environment Programme (2013). *Sustainable Public Procurement: A Global Review*. https://globalecolabelling.net/assets/Documents/unep-spp-report.pdf.

United Nations Environment Programme (2015) *LIRA Guidance: UNEP Guidance on the Development of Legal and Institutional Infrastructures and Measures for Recovering Costs of National Administration for Sound Management of Chemicals.* https://www.unenvironment.org/resources/report/lira-guidance.

United Nations Environment Programme (2016). The Kigali amendment to the Montreal protocol: another global commitment to stop climate change, 8 December. https://www.unenvironment.org/news-and-stories/news/kigali-amendment-montreal-protocol-another-global-commitment-stop-climate. Accessed 1 January 2019.

United Nations Environment Programme (2018). OzonAction: national ozone unit contacts, November. http://web.unep.org/ozonaction/resources/national-ozone-unit-contacts. Accessed 1 January 2019.

United States Centers for Disease Control and Prevention (2015). Hierarchy of controls, 13 January. https://www.cdc.gov/niosh/topics/hierarchy/default.html. Accessed 1 January 2019.

United States Environmental Protection Agency (2016). Benefits of addressing HFCs under the Montreal Protocol, 20 July. https://www.epa.gov/ozone-layer-protection/benefits-addressing-hfcs-under-montreal-protocol. Accessed 1 January 2019.

United States Environmental Protection Agency (2018). Guidelines for preparing economic analyses, 31 January. https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses. Accessed 1 January 2019.

United States National Aeronautics and Space Administration (2015). NASA study shows that common coolants contribute to ozone depletion, 22 October. https://www.nasa.gov/press-release/goddard/nasa-study-shows-that-common-coolants-contribute-to-ozone-depletion. Accessed 1 January 2019.

United States Occupational Safety and Health Administration (2012). Hazard communication standard: safety data sheets. https://www.osha.gov/Publications/OSHA3514.html. Accessed 1 January 2019.

United States Occupational Safety and Health Administration (2013). *Hazard Communication Standard: Labels and Pictograms*. https://www.osha.gov/Publications/OSHA3636.pdf.

Videras, J. and Alberini, A. (2007). The appeal of voluntary environmental programs: which firms participate and why? *Contemporary Economic Policy*. 18(4), 449-460. https://doi.org/10.1111/j.1465-7287.2000.tb00041.x.

Wang, Y., Wu, E., Gao, X. and Ding, Q. (2016). Global governance on chemical sound management and challenges in Asia-Pacific region. *Procedia Environmental Sciences* 31, 911-916. https://doi.org/10.1016/J.PROENV.2016.02.109.

World Business Council for Sustainable Development (2015). *Towards a Social Capital Protocol: A Call for Collaboration*. https://www.wbcsd.org/Programs/People/Social-Impact/Resources/Towards-a-Social-Capital-Protocol-A-Call-for-Collaboration.

World Business Council for Sustainable Development (2018). WBCSD launches first-of-its-kind guidance for the chemical industry to assess sustainability across its product portfolio, 17 April. https://www.wbcsd.org/Programs/Circular-Economy/Factor-10/Sector-Deep-Dives/News/guidance-for-the-chemical-industry-to-assess-sustainability-across-its-product-portfolio. Accessed 1 January 2019.

World Health Organization (WHO) (2017). *WHO Guidelines on Protecting Workers from Potential Risks of Manufactured Nanomaterials*. http://apps.who.int/iris/bitstream/handle/10665/259671/9789241550048-eng.pdf;jsessionid=2FD1722707BDE8E98B9B1D9F345DE46E?sequence=1.

World Health Organization (2018a). International Programme on Chemical Safety: International Chemical Safety Cards. http://www.who.int/ipcs/publications/icsc/en/. Accessed 3 January 2019.

World Health Organization (2018b). The Inter-Organization Programme for the Sound Management of Chemicals. http://www.who.int/iomc/en/. Accessed 1 January 2019.

Zhu, J., Liu, J.G., Hu, J. And Yi, S. (2016). Socio-economic analysis of the risk management of hexabromocyclododecane (HBCD) in China in the context of the Stockholm Convention. *Chemosphere* 150, 520-527. https://doi.org/10.1016/j.chemosphere.2015.11.007.

## Chapter 5

Anastas, P.T., Constable, D.J.C. and Jiménez-González, C.C. (eds.) (2018). Green Metrics. Handbook of Green Chemistry series. Wiley-VCH. https://www.wiley.com/en-ch/Green+Metrics,+Volume+11-p-9783527695270.

Ashford, N.A. (2013). Reducing physical hazards: encouraging inherently safer production. In *Designing Safer Chemicals. Handbook of Green Chemistry.* Anastas, P. T., Boethling, R. and Votchkova, A. (eds). Weinheim: John Wiley & Sons. Chapter 17. 485-500. https://doi.org/10.1002/9783527628698.hgc111.

Babrauskas, V., Lucas, D., Eisenberg, D., Singla, V., Dedeo, M. and Blum, A. (2012). Flame retardants in building insulation: a case for re-evaluating building codes. *Building Research & Information* 40(6), 738-755. https://doi.org/10.1080/09613218.2012.744533.

Baker, M. (2018). Despite bans, toxic flame retardants continue to show up in pregnant women's blood, 5 February. *University of California San Francisco News Center*. https://www.ucsf.edu/news/2018/02/409746/toxic-flame-retardants-continue-show-up-pregnant-women. Accessed 30 August 2018.

Birnbaum, L.S. and Bergman, A. (2010). Brominated and chlorinated flame retardants: the San Antonio statement. *Environmental Health Perspectives* 118(12), A514-A515. https://doi.org/10.1289/ehp.1003088.

Brown-West, B. (2017). Walmart takes bold steps towards safer chemicals, 27 September. *GreenBiz*. https://www.greenbiz.com/article/walmart-takes-bold-steps-towards-safer-chemicals. Accessed 1 January 2019.

Burgos-Hernandez, M. (2009). *Strategy for Mercury Elimination in Public Hospitals of Sonora State, Mexico: Implementation of Two Research Projects for the Achievement of a Collaborative Agreement*. Lowell, MA: University of Massachusetts Lowell, ProQuest Dissertations Publishing. https://search.proquest.com/docview/304916652/fulltextPDF/28B244F47EA84E42PQ/1?accountid=28970.

Canadian Centre for Occupational Health and Safety (2017). OHS answers fact sheets: trichloroethylene, 3 January. https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/trichloroethylene.html. Accessed 30 August 2018.

Chao, E.L. and Henshaw, J.L. (2003). Methylene chloride. https://www.osha.gov/Publications/osha3144.html. Accessed 1 January 2019.

Clean Production Action (2017). *GreenScreen® for Safer Chemicals Hazard Assessment Guidance, Version 1.3*. 2nd edn. https://www.greenscreenchemicals.org/static/ee_images/uploads/resources/GreenScreen_Guidance_v1.3(2e)_Feb_2017_final.pdf.

Damalas, C.A. and Koutroubas, S.D. (2018). Current status and recent developments in biopesticide use. *Agriculture* 8(1), 1-6. https://doi.org/10.3390/agriculture8010013.

Data Commons (n.d.). Find healthier substances. https://commons.healthymaterials.net/. Accessed 17 November 2018.

Eladak, S., Grisin, T., Moison, D., Guerquin, M.-J., N'Tumba-Byn, T., Pozzi-Gaudin, S., Benachi, A., Livera, G., Rouiller-Fabre, V. and Habert, R. (2015). A new chapter in the bisphenol A story: bisphenol S and bisphenol F are not safe alternatives to this compound. *Fertility and Sterility* 103(1), 11-21. https://doi.org/10.1016/J.FERTNSTERT.2014.11.005.

European Chemicals Agency (2011). *Guidance on the Preparation of an Application for Authorisation. Version 1*. https://echa.europa.eu/documents/10162/13643/authorisation_application_en.pdf.

European Chemicals Agency (2013). *Evaluation of New Scientific Evidence concerning DINP and DIDP: In Relation to Entry 52 of Annex XVII to REACH Regulation (EC) No 1907/2006. Final Review Report*. https://echa.europa.eu/documents/10162/31b4067e-de40-4044-93e8-9c9ff1960715.

European Chemicals Agency (2014). Updated guidance on the preparation of an Annex XV dossier for the identification of substances of very high concern, 12 February. https://echa.europa.eu/de/view-article/-/journal_content/title/updated-guidance-on-the-preparation-of-an-annex-xv-dossier-for-the-identification-of-substances-of-very-high-concern. Accessed 30 August 2018.

European Chemicals Agency (2018). *Strategy to Promote Substitution to Safer Chemicals through Innovation*. https://echa.europa.eu/documents/10162/2792271/mb_58_2017_2_annex_strategy_substitution_safer_alternatives_en.pdf/d1c31c63-4047-e7be-75d1-12320a4a8489.

European Commission (2006). Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the registration, evaluation, authorization and restriction of chemicals (REACH), establishing a European chemicals agency, amending directive 1999/4. *Official Journal of the European Union* L(136), 3-281. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:136:0003:0280:en:PDF.

European Commission (2017). *Impacts of REACH Authorisation – Final Report.* http://ec.europa.eu/docsroom/documents/26847.

Fantke, P. and Ernstoff, A. (2018). LCA of chemicals and chemical products. In *Life Cycle Assessment.* Hauschild, M.Z., Rosenbaum, R.K. and Olsen, S.I. (eds.). Cham: Springer. Chapter 31. 783-815. https://doi.org/10.1007/978-3-319-56475-3_31.

Finkbeiner, M., Ackermann, R., Bach, V., Berger, M., Brankatschk, G., Chang, Y.-J., Grinberg, M., Lehmann, A., Martínez-Blanco, J., Minkov, N., Neugebauer, S., Scheumann, R., Schneider, L. and Wolf, K. (2014). Challenges in life cycle assessment: an overview of current gaps and research needs. In *Background and Future Prospects in Life Cycle Assessment.* Klöpffer, W. (ed.). Dordrecht: Springer. Chapter 7. 207-258. https://doi.org/10.1007/978-94-017-8697-3_7.

Fisher, J., Varenne, B., Narvaez, D. and Vickers, C. (2018). The Minamata Convention and the phase down of dental amalgam. *Bulletin of the World Health Organization* 96(6), 436-438. https://doi.org/10.2471/BLT.17.203141.

Geiser, K., Tickner, J., Edwards, S. and Rossi, M. (2015). The architecture of chemical alternatives assessment. *Risk Analysis* 35(12), 2152-2161. https://doi.org/10.1111/risa.12507.

González, J.M.F. (2016). *Análisis y Diagnóstico de Políticas Agroambientales en Cuba: Fortalecimiento de las Políticas Agroambientales en los Países de América Latina y el Caribe Proyecto GCP/RLA/195/BRA*. Havana: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-i5559s.pdf.

Government of Canada (2018). Combined government discussion paper and science committee report on informed substitution, 28 August. https://www.canada.ca/en/health-canada/services/chemical-substances/chemicals-management-plan/science-committee/meeting-records-reports/combined-government-discussion-paper-science-committee-report-informed-substitution.html. Accessed 1 January 2019.

Grappi, S., Romani, S. and Barbarossa, C. (2017). Fashion without pollution: how consumers evaluate brands after an NGO campaign aimed at reducing toxic chemicals in the fashion industry. *Journal of Cleaner Production* 149, 1164-1173. https://doi.org/10.1016/J.JCLEPRO.2017.02.183.

Greenpeace International (2018). Destination zero: seven years of detoxing the clothing industry, 12 July. https://www.greenpeace.org/international/publication/17612/destination-zero/. Accessed 30 August 2018.

Harney, J., Nemhauser, J., Reh, C. and Trout, D. (2003). *NIOSH Health Hazard Evaluation Report: HETA #99-0260-2906*. Cincinnati: National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/hhe/reports/pdfs/1999-0260-2906.pdf

Hartmann, S. and Klaschka, U. (2017). Interested consumers' awareness of harmful chemicals in everyday products. *Environmental Sciences Europe* 29(1), 29. https://doi.org/10.1186/s12302-017-0127-8.

Health Care Without Harm (2018). Switching to alternatives. https://noharm-global.org/issues/global/switching-alternatives. Accessed 1 January 2019.

Hogue, C. (2013). Assessing alternatives to toxic chemicals: governments, businesses, and now the National Academy of Sciences consider how to avoid "regrettable substitution". *Chemical and Engineering News* 91(50), 19-20. https://cen.acs.org/articles/91/i50/Assessing-Alternatives-Toxic-Chemicals.html.

Ichihara, G., Kitoh, J., Li, W., Ding, X., Ichihara, S. and Takeuchi, Y. (2012). Neurotoxicity of 1-bromopropane: evidence from animal experiments and human studies. *Journal of Advanced Research* 3(2), 91-98. https://doi.org/10.1016/J.JARE.2011.04.005.

Intergovernmental Forum on Chemical Safety (2008). *Sixth Session of the Intergovernmental Forum on Chemical Safety – Final Report*. http://www.who.int/ifcs/documents/forums/forum6/f6_finalreport_en.pdf.

International Organisation for Biological Control, International Biocontrol Manufacturers Association and Pesticide Action Network (2015). *Integrated Pest Management: Working with Nature*. https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/integrated-pest-management-working-with-nature.pdf.

Israel, B. (2013). California to unveil new flammability standard to avoid chemicals in furniture: the new rules would cut down on the use of flame retardants that have been linked to human health effects, 8 February. *Scientific American*. https://www.scientificamerican.com/article/california-to-unveil-new-flammability-standard-to-avoid-chemicals-in-furniture/. Accessed 1 January 2019.

Jacobs, M.M., Massey, R.I., Tenney, H. and Harriman, E. (2014). Reducing the use of carcinogens: the Massachusetts experience. *Reviews on Environmental Health* 29(4), 319-340. https://doi.org/10.1515/reveh-2014-0048.

Jacobs, M.M., Malloy, T.F., Tickner, J.A. and Edwards, S. (2015). Alternatives assessment frameworks: research needs for the informed substitution of hazardous chemicals. *Environmental Health Perspectives* 124(3), 265-280. https://doi.org/10.1289/ehp.1409581.

Jamarani, R., Erythropel, H., Nicell, J., Leask, R. and Marić, M. (2018). How green is your plasticizer? Polymers 10(8), 834-851. https://doi.org/10.3390/polym10080834.

Lavoie, E.T., Heine, L.G., Holder, H., Rossi, M.S., Lee, R.E., Connor, E.A., Vrabel, M.A., DiFiore, D.M. and Davies, C.L. (2010). Chemical alternatives assessment: enabling substitution to safer chemicals. *Environmental Science & Technology* 44(24), 9244-9249. https://doi.org/10.1021/es1015789.

MacCarthy, L. (2017). Target to remove harmful chemicals from products, invest in green chemistry, 26 January. *Sustainable Brands*. https://sustainablebrands.com/read/product-service-design-innovation/target-to-remove-harmful-chemicals-from-products-invest-in-green-chemistryhttps://www.sustainablebrands.com/news_and_views/products_design/libby_maccarthy/target_commits_remove_harmful_chemicals_products_inve. Accessed 1 January 2019.

O'Brien, M. (2000). *Making Better Environmental Decisions: An Alternative to Risk Assessment*. Cambridge, MA: MIT Press. https://mitpress.mit.edu/books/making-better-environmental-decisions.

Office of Technical Assistance and Technology (2015). *Shawmut Corporation Eliminating TCE Use by Switching to a Hot-Melt Adhesive Process*. https://www.turi.org/TURI_Publications/Case_Studies/Coatings/Shawmut_Corporation_OTA_2015.

Organisation for Economic Co-operation and Development (2018). eChemPortal: global portal to information on chemical substances. http://www.oecd.org/chemicalsafety/risk-assessment/echemportalglobalportaltoinformationonchemicalsubstances.htm. Accessed 1 January 2019.

Organisation for Economic Co-operation and Development (n.d). OECD substitution and alternatives assessment toolbox. http://www.oecdsaatoolbox.org/. Accessed 1 January 2019.

Persistent Organic Pollutants Review Committee (2012). *Evaluation of Non-Chemical Alternatives to Endosulfan*. Geneva: Secretariat of the Stockholm Convention. http://synergies.pops.int/2013COPsExCOPs/Documents/tabid/2915/language/en-US/Default.aspx.

Pesticide Action Network UK (2017). Phasing out HHPs in Costa Rica. http://www.pan-uk.org/phasing-out-hhps-costa-rica/. Accessed 17 February 2019.

Rochester, J.R. and Bolden, A.L. (2015). Bisphenol S and F: a systematic review and comparison of the hormonal activity of bisphenol A substitutes. *Environmental Health Perspectives* 123(7), 643-50. https://doi.org/10.1289/ehp.1408989.

Sackmann, K., Reemtsma, T., Rahmberg, M. and Bunke, D. (2018). Impact of European chemicals regulation on the industrial use of plasticizers and patterns of substitution in Scandinavia. Environment International 119, 346-352. https://doi.org/10.1016/j.envint.2018.06.037.

Secretariat of the Stockholm Convention (2013). Sixth meeting of the Conference of the Parties to the Stockholm Convention: decisions, 10 May. http://chm.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP6/tabid/3074/mctl/ViewDetails/EventModID/870/EventID/396/xmid/10240/Default.aspx. Accessed 1 January 2019.

Secretariat of the Strategic Approach to International Chemicals Management (2015). *Report of the International Conference on Chemicals Management on the Work of its Fourth Session*. http://www.saicm.org/Portals/12/documents/meetings/ICCM4/doc/K1606013_e.pdf.

Siddiqi, M.A., Laessig, R.H. and Reed, K.D. (2003). Polybrominated diphenyl ethers (PBDEs): new pollutants – old diseases. *Clinical Medicine & Research* 1(4), 281-90. https://doi.org/10.3121/cmr.1.4.281.

Sinsheimer, P. (2010). *Developing Regulatory Methods for Integrating Life Cycle Assessment into Alternatives Analysis for Identifying Safer Substitutes for Hazardous Products*. Oakland, CA: State of California Department of Toxic Substances Control. https://www.dtsc.ca.gov/upload/sinsheimer.pdf.

State of California Department of Consumer Affairs. (2014). *Technical Bulletin 117-2013: Requirements, Test Procedure and Apparatus for Testing the Smolder Resistance of Materials Used in Upholstered Furniture*. https://myhfa.org/wp-content/uploads/2014/03/TB117-2013-QA.pdf.

State of California Department of Toxic Substances Control (2009). *Topic 4: Alternatives Assessment with Life Cycle Thinking*. https://dtsc.ca.gov/SCP/GRSP/upload/Alternatives-Analysis.pdf.

State of California Department of Toxic Substances Control (2012). *Division 4.5, Title 22, California Code of Regulations Chapter 55: California Safer Consumer Products*. http://www.dtsc.ca.gov/LawsRegsPolicies/Regs/upload/Text-of-Final-Safer-Consumer-Products-Regulations-2.pdf.

State of California Department of Toxic Substances Control (2017). Alternatives analysis guide, version 1.0. http://www.dtsc.ca.gov/SCP/AlternativesAnalysisGuidance.cfm. Accessed 4 June 2018

Sturcken, E. (2017). Walmart effect: retailers lead the way on chemical safety at a critical time, 10 October. *Environmental Defense Fund*. https://www.edf.org/blog/2017/10/10/walmart-effect-retailers-lead-way-chemical-safety-critical-time. Accessed 1 January 2019.

SUBSPORT (n.d.). SUBSPORT: substitution support portal. https://www.subsport.eu/. Accessed 1 January 2019.

Tickner, J.A., Geiser, K., Rudisill, C. and Schifano, J.N. (2013). Alternatives assessment in regulatory policy: history and future directions. In *Chemical Alternatives Assessments*. Hester, R.E. and Harrison, R.M. (eds.). Cambridge:Royal Society of Chemistry. Chapter 11. 256-295. https://doi.org/10.1039/9781849737234-00256.

Tickner, J.A., Schifano, J.N., Blake, A., Rudisill, C. and Mulvihill, M.J. (2015). Advancing safer alternatives through functional substitution. *Environmental Science & Technology* 49(2), 742-749. https://doi.org/10.1021/es503328m.

Tickner, J.A. and Jacobs, M. (2016). *Improving the Identification, Evaluation, Adoption and Development of Safer Alternatives: Needs and Opportunities to Enhance Substitution Efforts within the Context of REACH*. Lowell, MA. University of Massachusetts Lowell. https://echa.europa.eu/documents/10162/13630/substitution_capacity_lcsp_en.pdf.

Tickner, J.A., Jacobs, M., Malloy, T., Buck, T., Stone, A., Blake, A. and Edwards, S. (2018). Advancing alternatives assessment for safer chemical substitution: a research and practice agenda. *Integrated Environmental Assessment and Management*. https://doi.org/10.1002/ieam.4094.

Tomar, R.S., Budroe, J.D. and Cendak, R. (2013). *Evidence on the Carcinogenicity of Diisonoyl Phthalate (DINP)*. Sacramento, CA: California Environmental Protection Agency. https://oehha.ca.gov/media/downloads/proposition-65/chemicals/dinphid100413.pdf.

Toxics Use Reduction Institute (2013). *The Commons Principles for Alternatives Assessment: Addressing Chemicals of Concern to Human Health or the Environment*. https://www.turi.org/TURI_Publications/TURI_Chemical_Fact_Sheets/Commons_Principles_for_Alternatives_Assessment.

Toxics Use Reduction Institute (2017). *Toxics Use Reduction and Resource Conservation: Competitiveness Impacts for Massachusetts Businesses.* https://www.turi.org/TURI_Publications/TURI_Reports/Competitiveness_Impacts_for_Massachusetts_Businesses/Toxics_Use_Reduction_and_Resource_Conservation_Competitiveness_impacts_for_Massachusetts_Businesses.

United Nations Environment Programme (2014). *Phasing-out Methyl Bromide in Developing Countries: A Success Story and its Challenges*. http://www.unep.fr/ozonaction/information/mmcfiles/7674-e-Phasing_out_methyl_bromide_in_developing_countries.pdf.

United Nations Environment Programme (2016). *Lessons from Countries Phasing Down Dental Amalgam Use.* https://wedocs.unep.org/bitstream/handle/20.500.11822/11624/Dental.Amalgam.10mar2016.pages.WEB.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2017). Life cycle initiative. https://www.lifecycleinitiative.org/. Accessed 1 January 2019.

United Nations Environment Programme and World Health Organization (2014). *Promoting the Phase Down of Dental Amalgam in Developing Countries*. https://wedocs.unep.org/bitstream/handle/20.500.11822/13865/dental_mercury_phase_down_project_brochure_FINAL_lr.pdf?sequence=1&isAllowed=y.

United Nations Industrial Development Organization (2018). National cleaner production centres (NCPCs) and networks. https://www.unido.org/our-focus/cross-cutting-services/partnerships-prosperity/networks-centres-forums-and-platforms/national-cleaner-production-centres-ncpcs-networks. Accessed 31 August 2018.

United States Centers for Disease Control and Prevention (2008). Neurologic illness associated with occupational exposure to the solvent 1-bromopropane – New Jersey and Pennsylvania, 2007-2008. *Morbidity and Mortality Weekly Report* 57(48), 1300-1302. http://www.ncbi.nlm.nih.gov/pubmed/19052528.

United States Environmental Protection Agency (2017). Design for the environment programs, initiatives and projects, 19 April. http://www.epa.gov/saferchoice/design-environment-programs-initiatives-and-projects. Accessed 1 January 2019.

United States Environmental Protection Agency (2018) CompTox chemicals dashboard: what is the comptox chemicals dashboard? 13 December. https://www.epa.gov/chemical-research/comptox-chemicals-dashboard. Accessed 1 January 2019.

United States National Research Council (2014). *A Framework to Guide Selection of Chemical Alternatives*. Washington, DC: National Academies Press. http://www.nap.edu/catalog/18872.

United States National Toxicology Program (2011). *Toxicology and Carcinogenesis Studies of 1-bromopropane in F344/N Rats and B6C3F1 Mice (Inhalation Studies)*. Durham, NC: US Department of Health and Human Services. https://ntp.niehs.nih.gov/results/pubs/longterm/reports/longterm/tr500580/listedreports/tr564/index.html.

United States Natural Resources Defense Council (2018). The Home Depot to be third major U.S. retailer to ban deadly paint strippers, 19 June. https://www.nrdc.org/media/2018/180619. Accessed 30 August 2018.

United States Occupational Safety and Health Administration (n.d.). Transitioning to safer chemicals: a toolkit for employers and workers. https://www.osha.gov/dsg/safer_chemicals/index.html. Accessed 1 January 2019.

Walmart (2018). Walmart commitment to sustainable chemistry. https://www.walmartsustainabilityhub.com/sustainable-chemistry/sustainable-chemistry-policy. Accessed 1 January 2019.

Weber, R., Fantke, P., Hamouda, A. Ben and Mahjoub, B. (2018). *20 Case Studies on How to Prevent the Use of Toxic Chemicals Frequently Found in the Mediterranean Region*. Barcelona: Regional Activity Centre for Sustainable Consumption and Production (SCP/RAC). http://www.cprac.org/en/news-archive/general/we-are-surrounded-by-toxic-chemicals-scp/rac-provides-20-case-studies-to-preven.

Wendschlag, H. (2015). *Business Guide to Safer Chemicals in the Supply Chain Including Alternatives Assessment*. Shrewsbury: Chemical Watch. https://www.greenscreenchemicals.org/static/ee_images/uploads/resources/HP_GREEN_SCREEN_ARTICLE.pdf.

World Health Organization (2015). *Developing National Strategies for Phasing Out Mercury Containing Thermometers and Sphygmomanometers in Health Care, Including in the Context of the Minamata Convention on Mercury: Key Considerations and Step-by-Step Guidance.* http://apps.who.int/iris/bitstream/handle/10665/259448/9789241508339-eng.pdf;jsessionid=A8006FEAC3880B70D81CA55703F711E1?sequence=1.

## Chapter 6

Abu Bakar, H.T., Han Siong, P., Koy Yan, C., Kidam, K., Wijayanuddin Ali, M., Hassim, M.H. and Kamarden, H. (2017). Analysis of main accident contributor according to process safety management elements failure. *Chemical Engineering Transactions* 56, 991-996. https://doi.org/10.3303/CET1756166.

Ahmad, I., Rehan, M., Balkhyour, M., Abbas, M., Basahi, J., Balkhyour, M.A., Basahi, J.M., Almeelbi, T. and Ismail, I.M.I. (2016). Review of environmental pollution and health risks at motor vehicle repair workshops: challenges and perspectives for Saudi Arabia. *International Journal of Agricultural and Environmental Research* 2(1), 1-23. https://pdfs.semanticscholar.org/f80b/9eaaa61f97b2f5320d9073050f838c575b03.pdf.

Alfers, L. (2013). *The Ghana National Health Insurance Scheme: Barriers to Access to Informal Workers*. WIEGO Working Paper (Social Protection) No. 30. Cambridge, MA and London: Women in Employment Globalizing and Organizing. http://www.wiego.org/sites/default/files/publications/files/Alfers-Ghana-Health-Insur-Informal-Workers-WIEGO-WP30.pdf.

Alfers, L., Lund, F. and Moussié (2018). *Informal Workers & The Future of Work: A Defence of Work-Related Social Protection*. WIEGO Working Paper No. 37. Manchester: Women in Employment Globalizing and Organizing. http://www.wiego.org/sites/default/files/publications/files/Alfers_Informal_Workers_Social_Protection_WIEGO_WP37.pdf.

Baranzini, D., Wood, M., Krausmann, E. and Van Wijk, L. (2018). Capacity building measures for chemical accident prevention and preparedness: benchmark of EU neighbourhood countries. *International Journal of Disaster Risk Reduction* 31, 770-780. https://doi.org/10.1016/J.IJDRR.2018.07.023.

Benjamin, N., Beegle, K., Recanatini, F. and Santini, M. (2014). *Informal Economy and the World Bank*. Policy Research Working Paper No. 6888. Washington, D.C.: The World Bank. http://documents.worldbank.org/curated/en/416741468332060156/pdf/WPS6888.pdf.

Bhandubanyong, P. and Pearce, T.H. (2017). Appraisal of SME casting industry in Thailand. *International Scientific Journal of Engineering and Technology* 1(1), 1-8. http://www.responsiblemines.org/wp-content/uploads/2018/05/059_ASGM-Formalization.pdf.

Center for Chemical Process Safety (2017). Pre-conference course: CCPS overview of risk based process safety, 11 September. https://www.aiche.org/ccps/conferences/ccps-global-summit-on-process-safety/2017/events/ccps-overview-risk-based-process-safety. Accessed 2 June 2018.

Chakraborty, P., Selvaraj, S., Nakamura, M., Balasubramanian, P., Cincinelli, A. and Bang, J. (2018). PCBs and PCDD/Fs in soil from informal e-waste recycling sites and open dumpsites in India: levels, congener profiles and health risk assessment. *Science of the Total Environment* 621, 930-938. https://doi.org/10.1016/J.SCITOTENV.2017.11.083.

Charmes, J. (2012). The informal economy worldwide: trends and characteristics. *Margin: The Journal of Applied Economic Research* 6(2), 103-132. https://doi.org/10.1177/097380101200600202.

de Haan, J. and Turner, B. (2018). *Handbook: Developing National ASGM Formalization Strategies within National Action Plans*. Geneva: United Nations Institute for Training and Research and United Nations Environment Programme. https://unitar.org/cwm/sites/unitar.org.cwm/files/uploads/formalization_handbook_e_web_final.pdf.

European Commission (2017) Major accident hazards: the Sevezo Directive – technological disaster reduction, 24 August. http://ec.europa.eu/environment/seveso/index.htm. Accessed 28 December 2018.

European Commission Joint Research Centre and United Nations Economic Commission for Europe (2016). *An Overview of Methodologies for Hazard Rating of Industrial Sites*. https://minerva.jrc.ec.europa.eu/en/shorturl/minerva/jrc101613engfinal_hazard_rating_guide3nov_2016onlinepdf.

Girgin, S., Necci, A. and Krausmann, E. (2017). Natech hazard and risk assessment. In *Words into Action Guidelines: National Disaster Risk Assessment Hazard Specific Risk Assessment*. Geneva: United Nations Office for Disaster Risk Reduction. Chapter 9. 91-98. https://www.unisdr.org/files/52828_09natechhazardandriskassessment.pdf.

Gori, A., Gidaris, I., Elliott,, J.R., Padgett, J., Loughran, K., Bedient, P.B., Panakkal, P. and Juan, A. (2018). NH33D-1038: investigating flood-induced cascading impacts to Houston's road network and emergency service accessibility during Hurricane Harvey. *American Geophysical Union Fall Meeting*. https://agu.confex.com/agu/fm18/meetingapp.cgi/Paper/438218. Accessed 28 December 2018.

Gyenes, Z. and Wood, M.H. (2014). *Lessons Learned from Major Accidents Having Significant Impact on the Environment*. Symposium Series No 159, Hazards 24. Edinburgh: Institute of Chemical Engineers. https://doi.org/10.13140/2.1.2897.6005.

Hassan, S.A. (2012). *Health, Safety and Environmental Practices in the Construction Sector of Pakistan*. Uppsala: Upsala University. http://www.diva-portal.org/smash/get/diva2:562426/FULLTEXT01.pdf.

He, G., Zhang, L., Lu, Y. and Mol, A.P.J. (2011). Managing major chemical accidents in China: towards effective risk information. *Journal of Hazardous Materials* 187(1-3), 171-181. https://doi.org/10.1016/J.JHAZMAT.2011.01.017.

He, Q.S. and Yang, Y.Y. (2012). Effect of EU environmental directives on chemical industries in Zhejiang. *Chemical Industry Times* 24, 75-77. https://www.researchgate.net/publication/285686566_Effect_of_EU_environmental_directives_on_chemical_industries_in_Zhejiang.

Heikkilä, A.-M., Malmén, Y., Nissilä, M. and Kortelainen, H. (2010). Challenges in risk management in multi-company industrial parks. *Safety Science* 48(4), 430-435. https://doi.org/10.1016/J.SSCI.2009.12.008.

Holmes, R. and Scott, L. (2016). *Extending Social Insurance to Informal Workers: A Gender Analysis*. ODI Working Paper 438. London: Overseas Development Institute. https://www.odi.org/sites/odi.org.uk/files/resource-documents/10620.pdf.

Hong, K.T., Surienty, L. and Hung, K.M. (2011). Occupational safety and health (OHS) in Malaysian Small and Medium Enterprise (SME) and effective safety management practices. *International Journal of Business and Technopreneurship* 1(2), 321-338. https://www.researchgate.net/publication/315765815_Occupational_Safety_and_Health_OSH_in_Malaysian_Small_and_Medium_Enterprise_SME_and_Effective_Safety_Management_Practices.

Inter-Agency Coordination Group for Industrial and Chemical Accidents (2017). *International Efforts for Industrial and Chemical Accidents Prevention, Preparedness and Response*. https://www.oecd.org/chemicalsafety/chemical-accidents/Brochure-International-efforts-for-industrial-and-chemical-accidents.pdf.

International Atomic Energy Agency (2006). *IAEA Safety Standards for Protecting People and the Environment: Application of the Management System for Facilities and Activities*. https://www-pub.iaea.org/mtcd/publications/pdf/pub1253_web.pdf.

International Institute for Environment and Development (2018). Addressing risks facing informal workers, April. https://www.iied.org/addressing-risks-facing-informal-workers. Accessed 27 December 2018.

International Labour Organization (1997). Social Security for the Informal Sector: Investigating the Feasibility of Pilot Projects in Benin, India, El Salvador and Tanzania. https://www.ilo.org/secsoc/information-resources/publications-and-tools/Discussionpapers/WCMS_207714/lang--en/index.htm.

International Labour Organization (2009). Convention C187 – promotional framework for occupational safety and health convention, 2006 (no. 187). https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C187. Accessed 27 December 2018.

International Labour Organization (2014). *Tackling Informality in E-Waste Management: The Potential of Cooperative Enterprises*. https://www.ilo.org/sector/Resources/publications/WCMS_315228/lang--en/index.htm.

International Labour Organization (2015a). *Recommendation No. 204 concerning the Transition from the Informal to the Formal Economy*. https://www.ilo.org/ilc/ILCSessions/104/texts-adopted/WCMS_377774/lang--en/index.htm.

International Labour Organization (2015b). *Small and Medium-sized Enterprises and Decent and Productive Employment Creation*. 1st edn. https://www.ilo.org/ilc/ILCSessions/104/reports/reports-to-the-conference/WCMS_358294/lang--en/index.htm.

International Labour Organization (2018a). *Women and Men in the Informal Economy: A Statistical Picture.* 3rd edn. https://www.ilo.org/global/publications/books/WCMS_626831/lang--en/index.htm.

International Labour Organization (2018b). Informal economy: a hazardous activity. https://www.ilo.org/safework/areasofwork/hazardous-work/WCMS_110305/lang--en/index.htm. Accessed 28 December 2018.

Jonkman, S.N., Godfroy, M., Sebastian, A. and Kolen, B. (2018). Brief communication: loss of life due to Hurricane Harvey. *Natural Hazards and Earth System Sciences* 18(4), 1073-1078. https://doi.org/10.5194/nhess-18-1073-2018.

Kidam, K. and Hurme, M. (2013). Method for identifying contributors to chemical process accidents. *Process Safety and Environmental Protection* 91(5), 367-377. https://doi.org/10.1016/J.PSEP.2012.08.002.

Kim, Y., Park, J. and Park, M. (2016). Creating a culture of prevention in occupational safety and health practice. *Safety and Health at Work* 7(2), 89-96. https://doi.org/10.1016/j.shaw.2016.02.002.

Krausmann, E., Cruz, A.M. and Salzano, E. (2017). *Natech Risk Assessment and Management: Reducing the Risk of Natural-Hazard Impact on Hazardous Installations*. 1st edn. Amsterdam: Elsevier Inc. https://www.elsevier.com/books/natech-risk-assessment-and-management/krausmann/978-0-12-803807-9.

Krausmann, E. and Salzano, E. (2017). Lessons learned from Natech events. In *Natech Risk Assessment and Management*. Elsevier. Chapter 3. 33-52. https://doi.org/10.1016/B978-0-12-803807-9.00003-6.

Kultida, B., Sunil, H., Cordia, C., Dung, T. and Jakkris, S. (2015). The integration of occupational health and safety into the development of eco-industrial parks. *Health and the Environment Journal* 6(1), 72-84. http://hej.kk.usm.my/pdf/HEJVol.6No.1/Article06.pdf.

Lajini, P. (2014). Importance of workers understanding of chemicals for safety – information, communication and safety culture. *African Newsletter on Occupational Health and Safety* 24(3), 60-61. https://issuu.com/tyoterveyslaitos/docs/african_newsletter_3-_2014_netti.

Legg, S., Olsen, K., Laird, I. and Hasle, P. (2015). Managing safety in small and medium enterprises. *Safety Science* 71, 189-196. https://doi.org/10.1016/j.ssci.2014.11.007.

Maiguashca, A.F. (2016). How can we save the poor from Latin America's informal economy? 29 April. *World Economic Forum*. https://www.weforum.org/agenda/2016/04/how-can-we-save-the-poor-from-latin-americas-informal-economy/. Accessed 27 December 2018.

Makhonge, P.W. (2014). Situation of chemical safety in small-scale enterprises in Kenya. *African Newsletter on Occupational Health and Safety* 24(3), 54-55. http://ihi.eprints.org/3022/1/Elikana_Lekei.pdf.

Makino, R. (2016). Stock market responses to chemical accidents in Japan: an event study. *Journal of Loss Prevention in the Process Industries* 44, 453-458. https://doi.org/10.1016/j.jlp.2016.10.019.

Massey, R. (2005). *Building a Healthy Economy: Chemicals Risk Management as a Driver of Development*. Stockholm: Swedish Chemicals Agency. http://www.ase.tufts.edu/gdae/Pubs/rp/KemiReport_05.pdf.

Massey, R. (2008). Sharing knowledge about chemicals: policy options for facilitating information flow. In *Options for State Chemicals Policy Reform – A Resource Guide.* Coffin, M. and Dunn, M.L. (eds.). Lowell, MA: Lowell Center for Sustainable Production. Chapter 2. 69-96. http://sustainableproduction.org/downloads/OptionsforStateChemicalsPolicyReform.pdf.

Micheli, G.J.L. and Cagno, E. (2010). Dealing with SMEs as a whole in OHS issues: warnings from empirical evidence. *Safety Science* 48(6), 729-733. https://doi.org/10.1016/J.SSCI.2010.02.010.

Mizoue, T., Huuskonen, M., Muto, T., Koskinen, K., Husman, K. and Bergstrom, M. (1999). Analysis of Japanese occupational health services for small- and medium-scale enterprises in comparison with the Finnish system. *Journal of Occupational Health* 41, 115-120. http://joh.sanei.or.jp/pdf/E41/E41_2_11.pdf.

Mrema, E.J., Ngowi, A.V., Kishinhi, S.S. and Mamuya, S.H. (2017). Pesticide exposure and health problems among female horticulture workers in Tanzania. *Environmental Health Insights* 11, 1-13. https://doi.org/10.1177/1178630217715237.

Mukim, M. (2011). *Industry and the Urge to Cluster: A Study of the Informal Sector in India*. Spatial Economics Research Centre (SERC) Discussion Papers. London: London School of Economics and Political Sciences. http://eprints.lse.ac.uk/33592/.

Necci, A., Krausmann, E. and Girgin, S. (2018). *Understanding Natech Risk Due to Storms – Analysis, Lessons Learned and Recommendations*. Joint Research Centre Technical Report JRC112987 (forthcoming). European Commission.

Nordlöf, H., Wiitavaara, B., Högberg, H. and Westerling, R. (2017). A cross-sectional study of factors influencing occupational health and safety management practices in companies. *Safety Science* 95, 92-103. https://doi.org/10.1016/J.SSCI.2017.02.008.

Nyirendaavwil, V., Chinniah, Y. and Agard, B. (2015). Identifying key factors for an occupational health and safety risk estimation tool in small and medium-size enterprises. *International Federation of Automatic Control* 48(3), 541-546. https://doi.org/10.1016/J.IFACOL.2015.06.137.

Okoh, P. and Haugen, S. (2014). A study of maintenance-related major accident cases in the 21st century. *Process Safety and Environmental Protection* 92(4), 346-356. https://doi.org/10.1016/J.PSEP.2014.03.001.

Organisation for Economic Co-operation and Development (2002). *Measuring the Non-Observed Economy: A Handbook*. http://www.oecd.org/sdd/na/1963116.pdf.

Organisation for Economic Co-operation and Development (2003). *Guiding Principles for Chemical Accident Prevention, Preparedness and Response*. http://www.oecd.org/chemicalsafety/chemical-accidents/guiding-principles-chemical-accident-prevention-preparedness-and-response.htm.

Organisation for Economic Co-operation and Development (2012). *Corporate Governance for Process Safety: OECD Guidance for Senior Leaders in High Hazard Industry.* http://www.oecd.org/env/ehs/chemical-accidents/corporategovernanceforprocesssafety.htm

Organisation for Economic Co-operation and Development (2015). *Addendum Number 2 to the OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response (2nd Edition) to Address Natural Hazards Triggering Technological Accidents (Natechs)*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2015)1&doclanguage=en.

Organisation for Economic Co-operation and Development (2018a). *Guidance on Change of Ownership in Hazardous Facilities*. http://www.oecd.org/chemicalsafety/chemical-accidents/oecd-guidance-on-change-of-ownership-in-hazardous-facilities.pdf.

Organisation for Economic Co-operation and Development (2018b). *Towards an All-Hazards Approach to Emergency Preparedness and Response: Lessons Learnt from Non-Nuclear Events*. https://www.oecd-nea.org/rp/pubs/2018/7308-all-hazards-epr.pdf.

Organisation for Economic Co-operation and Development (2018c). *Developing a Methodology to Quantify the Benefits of Regulations for Chemical Accidents Prevention, Preparedness and Response*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2018)3&doclanguage=en.

Paul, H.L., Antunes, P., Covington, A.D., Evans, P. and Phillips, P.S. (2013). Bangladeshi leather industry: an overview of recent sustainable developments. *Journal Society of Leather Technologists and Chemists* 91(1), 25-32. https://www.researchgate.net/publication/235609270_Bangladeshi_Leather_Industry_An_Overview_of_Recent_Sustainable_Developments.

Reniers, G. and Amyotte, P. (2012). Prevention in the chemical and process industries: future directions. *Journal of Loss Prevention in the Process Industries* 25(1), 227-231. https://doi.org/10.1016/J.JLP.2011.06.016.

Reniers, G., Cuypers, S. and Pavlova, Y. (2012). A game-theory based Multi-plant Collaboration Model (MCM) for cross-plant prevention in a chemical cluster. *Journal of Hazardous Materials* 209-210, 164-176. https://doi.org/10.1016/j.jhazmat.2012.01.004.

Rockefeller Foundation (2013). *Health Vulnerabilities of Informal Workers.* https://assets.rockefellerfoundation.org/app/uploads/20130528214745/Health-Vulnerabilities-of-Informal-Workers.pdf.

Rongo, L.M.B. (2005). Health risks related to chemicals used in small scale industries in the informal sector in Dar es Salaam, Tanzania. *East African Journal of Public Health* 2(2), 12-17. http://www.bioline.org.br/pdf?lp05011.

Rongo, L.M.B., Barten, F., Msamanga, G.I., Heederik, D. and Dolmans, W.M.V. (2004). Occupational exposure and health problems in small-scale industry workers in Dar es Salaam, Tanzania: a situation analysis. *Occupational Medicine* 54, 42-46. https://www.ncbi.nlm.nih.gov/pubmed/14963253.

Sebastian, A., Lendering, K.T., Kothuis, B.L.M., Brand, A.D., Jonkman, S.N., van Gelder, P.H.A.J.M., Godfroij, M., Kolen, B., Comes, M., Lhermitte, S.L.M., Meesters, K.J.M.G., van de Walle, B.A., Ebrahimi Fard, A., Cunningham, S., Khakzad Rostami, N. and Nespeca, V. (2017). *Hurricane Harvey Report: A Fact-Finding Effort in the Direct Aftermath of Hurricane Harvey in the Greater Houston Region*. Delft: Delft University Publishers. https://repository.tudelft.nl/islandora/object/uuid%3A54c24519-c366-4f2f-a3b9-0807db26f69c?collection=research.

Seccatore, J., Veiga, M.M., Origliasso, C., Marin, T. and Tomi, G. (2014). An estimation of the artisanal small-scale production of gold in the world. *Science of The Total Environment* 496, 662-667. http://doi.org/10.1016/j.scitotenv.2014.05.003.

Sengupta, A., Bandyopadhyay, D., van Westen, C.J. and van der Veen, A. (2015). An evaluation of risk assessment framework for industrial accidents in India. *Journal of Loss Prevention in the Process Industries* 41, 295-302. https://doi.org/10.1016/J.JLP.2015.12.012.

Singh, T.S., Ratshikhopha, E., Zubaydah, K., Fourie, A., Dikeledi Matuka, O., Bartie, D. and Dayal, P. (2011). Biological and chemical risks in the informal sector. *Occupational Health Southern Africa* 18(6), 4-12. https://www.researchgate.net/publication/278269654_Singh_et_al_Biological_and_chemical_risks_in_the_informal_sector_OHSA_2012.

Sklet, S (2004). Comparison of some selected methods for accident investigation. *Journal of Hazardous Materials* 111 (2004) 29-37. https://doi.org/10.1016/j.jhazmat.2004.02.005.

Targoutzidis, A., Koukoulaki, T., Schmitz-Felten, E., Kuhl, K., Hengel, K.M.O., Rijken, E., Broek, K. Van den and Klüser, R. (2014). *The Business Case for Safety and Health at Work: Cost-benefit Analyses of Interventions in Small and Medium-sized Enterprises*. European Agency for Safety and Health at Work. https://doi.org/10.2802/32988.

Tauseef, S.M., Abbasi, T. and Abbasi, S.A. (2011). Development of a new chemical process-industry accident database to assist in past accident analysis. *Journal of Loss Prevention in the Process Industries* 24(4), 426-431. https://doi.org/10.1016/J.JLP.2011.03.005.

Taylor, R., May, J., Weyman, A., and Carhart, N. (2017). Understanding organisational and cultural precursors to events. *Proceedings of the ICE -Forensic Engineering*, 170(3), 124-133. https://doi.org/10.1680/jfoen.17.00006.

Thornton, R., Hatt, L., Field, E., Islam, M., Solís, F. and González, M.A. (2010). Social security health insurance for the informal sector in Nicaragua: a randomized evaluation. *Health Economics* 19(1), 181-206. https://doi.org/10.1002/hec.1635.

United Nations Environment Programme (2010). *A Flexible Framework for Addressing Chemical Accident Prevention and Preparedness: A Guidance Document*. https://www.preventionweb.net/publications/view/56412.

United Nations Environment Programme (2011). *Promoting Safer Operations and Emergency Preparedness in the Value Chain of the Chemical Sector: Case Study on APELL Implementation in China*. http://apell.eecentre.org/APELLCaseStudyChina.pdf.

United Nations Environment Programme (2012). *Analysis of Formalization Approaches in the Artisanal and Small-Scale Gold Mining Sector Based on Experiences in Ecuador, Mongolia, Peru, Tanzania and Uganda.* https://wedocs.unep.org/bitstream/handle/20.500.11822/11357/Formalization_Document_Final_June_2012.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2013). *Global Chemicals Outlook: Towards Sound Management of Chemicals*. http://wedocs.unep.org/bitstream/handle/20.500.11822/20200/unep_global_chemical.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme (2015). *Chemical Accident Prevention and Preparedness: Case Studies of Implementation*. Paris. http://www.capp.eecentre.org/Upload/files/Case_studies_of_implementation-CAPP.pdf.

United Nations Environment Programme (2017). *Promoting Chemical Safety Management in Ports and along Transport Routes of Dangerous Goods: Case Studies from Africa*. https://wedocs.unep.org/bitstream/handle/20.500.11822/20763/Promoting%20Chemical%20Safety%20Management%20in%20Ports%20and%20Transport%20Routes.pdf?sequence=1&isAllowed=y.

United Nations Office for Disaster Risk Reduction (2018). *Words into Action Guidelines – Man-Made and Technological Hazards: Practical Considerations for Addressing Man-Made and Technological Hazards in Disaster Risk Reduction*. https://www.unisdr.org/files/54012_manmadetechhazards.pdf.

United Nations Research Institute for Social Development (2010). Gender inequalities at home and in the market. In *Combating Poverty and Inequality: Structural Change, Social Policy and Politics*. Chapter 4. 107-131. http://www.unrisd.org/80256B3C005BCCF9/(httpAuxPages)/8BACF1B0908D70E1C125778900323600/$file/PovRepCh4.pdf.

United Nations Research Institute for Social Development (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030*. https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf.

United States Environmental Protection Agency (2018) Risk Management Plan (RMP) rule, 28 December. https://www.epa.gov/rmp. Accessed 1 January 2019.

Unnikrishnan, S., Iqbal, R., Singh, A. and Nimkar, I.M. (2015). Safety management practices in small and medium enterprises in India. *Safety and Health at Work* 6(1), 46-55. https://doi.org/10.1016/J.SHAW.2014.10.006.

van Oldenborgh, G.J., van der Wiel, K., Sebastian, A., Singh, R., Arrighi, J., Otto, F., Haustein, K., Li, S., Vecchi, G. and Cullen, H. (2017). Attribution of extreme rainfall from Hurricane Harvey, August 2017. *Environmental Research Letters* 12, 12. https://doi.org/10.1088/1748-9326/aa9ef2.

Vasina, M. (2018). *Health-related Practices and Perceptions among Waste Pickers. The Case of Mbeubeuss Waste Dump in Senegal*. Geneva: Graduate Institute of International and Development Studies. http://www.wiego.org/sites/default/files/resources/files/VASINA_Marine_Dissertation_Compressed.pdf.

Veiga, M,M., Angeloci-Santos, G. and and Meech, J.A. (2014). Review of barriers to reduce mercury use in artisanal bold mining. *The Extractive Industries and Society* 1(2), 351-61. https://doi.org/10.1016/j.exis.2014.03.004.

Verbano, C., Venturini, K. and Venturini, K. (2013). Managing risks in SMEs: a literature review and research agenda. *Journal of Technology Management & Innovation* 8(3), 33-34. https://doi.org/10.4067/S0718-27242013000400017.

World Health Organization (2018). *Chemical Releases Caused by Natural Hazard Events and Disasters: Information for Public Health Authorities*. https://www.who.int/ipcs/publications/natech/en/.

Yuan, X. and Wang, K. (2012). Study on safety management of small and medium-sized enterprises based on BBS. *Procedia Engineering* 45, 208-213. https://doi.org/10.1016/J.PROENG.2012.08.145.

Zhao, J., Joas, R., Abel, J., Marques, T. and Suikkanen, J. (2013). Process safety challenges for SMEs in China. *Journal of Loss Prevention in the Process Industries* 26(5), 880-886. https://doi.org/10.1016/J.JLP.2012.09.003.

Zheng, X., Xu, X., Akangbe Yekeen, T., Zhang, Y., Chen, A., Kim, S.S., Dietrich, K.N., Ho, S.-M., Lee, S.-A., Reponen, T. and Huo, X. (2016). Ambient air heavy metals in PM2.5 and potential human health risk assessment in an informal electronic-waste recycling site of China. *Aerosol and Air Quality Research* 16, 388-397. https://doi.org/10.4209/aaqr.2014.11.0292.

Zock, J.P. (2005). World at work: cleaners. *Occupational and Environmental Medicine* 62, 581-584. https://doi.org/10.1136/oem.2004.015032.

## Chapter 7

Bern University of Applied Sciences (2017). *Response-Inducing Sustainability Evaluation (RISE)*. https://www.hafl.bfh.ch/fileadmin/docs/Forschung_Dienstleistungen/Agrarwissenschaften/Nachhaltigkeitsbeurteilung/RISE/What_is_RISE.pdf.

Bey, N. (2018). Life cycle management. In *Life Cycle Assessment: Theory and Practice*. Hauschild, M.Z., Rosenbaum, R.K. and Olsen, S.I. (eds.). Cham: Springer. 519-544. http://doi.org/10.1007/978-3-319-56475-3_22.

European Commission (2010). Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). *Official Journal of the European Union* L (334), 17-119. http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32010L0075.

European Commission (2013). Commission Recommendation 2013/179/EU of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. *Official Journal of the European Union* L (124), 1-210. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013H0179.

Fantke, P., Ernstoff, A.S., Huang, L., Csiszar, S.A. and Jolliet, O. (2016). Coupled near-field and far-field exposure assessment framework for chemicals in consumer products. *Environment International* 94, 508-518. http://doi.org/10.1016/j.envint.2016.06.010.

Fantke, P. and Ernstoff, A. (2018). LCA of chemicals and chemical products. In *Life Cycle Assessment.* Hauschild, M.Z., Rosenbaum, R.K. and Olsen, S.I. (eds.). Cham: Springer International Publishing. 783-815. https://doi.org/10.1007/978-3-319-56475-3_31

Fantke, P., Huang, L., Overcash, M., Griffing, E. and Jolliet, O. (2019). Toward a life-cycle based alternatives assessment. In *Green Chemistry* (submitted).

Hauschild, M.Z. (2005). Assessing environmental impacts in a life-cycle perspective. *Environmental Science and Technology* 39, 81A-88A. http://doi.org/10.1021/es053190s.

Hauschild, M., Huijbregts, M.A.J. (eds.) (2015). *Life Cycle Impact Assessment*. Dordrecht: Springer. https://doi.org/10.1007/978-94-017-9744-3.

Hellweg, S. and Milà i Canals, L. (2014). Emerging approaches, challenges and opportunities in life cycle assessment. *Science* 344 (6188), 1109-1113. http://doi.org/10.1126/science.1248361.

Henderson, A.D., Hauschild, M.Z., van de Meent, D., Huijbregts, M.A.J., Larsen, H.F., Margni, M., McKone, T.E., Payet, J., Rosenbaum, R.K. and Jolliet, O. (2011). USEtox fate and ecotoxicity factors for comparative assessment of toxic emissions in life cycle analysis: sensitivity to key chemical properties. *International Journal of Life Cycle Assessment* 16, 701-709. http://doi.org/10.1007/s11367-011-0294-6.

Hottle, T.A., Bilec, M.M. and Landis, A.E. (2013). Sustainability assessments of bio-based polymers. *Polymer Degradation and Stability* 98, 1898-1907. http://doi.org/10.1016/j.polymdegradstab.2013.06.016.

International Organization for Standardization (2018). ISO 14000 family – environmental management. https://www.iso.org/iso-14001-environmental-management.html. Accessed 28 December 2018.

Ny, H., MacDonald, J.P., Broman, G., Ryoichi, Y. and Robert, K.-H. (2006). Sustainability constraints as system boundaries: an approach to making life-cycle management strategic. *Journal of Industrial Ecology* 10, 61-77. http://doi.org/10.1162/108819806775545349.

Pivnenko, K. and Astrup, T.F. (2016). The challenge of chemicals in material lifecycles. *Waste Management* 56, 1-2. http://doi.org/10.1016/j.wasman.2016.08.016.

Ridoutt, B., Fantke, P., Pfister, S., Bare, J., Boulay, A.-M., Cherubini, F., Frischknecht, R., Hauschild, M., Hellweg, S., Henderson, A., Jolliet, O., Levasseur, A., Margni, M., McKone, T., Michelsen, O., Milà i Canals, L., Page, G., Pant, R., Raugei, M., Sala, S., Saouter, E., Verones, F. and Wiedmann, T. ( 2015). Making sense of the minefield of footprint indicators. *Environmental Science & Technology* 49, 2601-2603. http://doi.org/10.1021/acs.est.5b00163.

Rosenbaum, R.K., Huijbregts, M.A.J., Henderson, A.D., Margni, M., McKone, T.E., van de Meent, D., Hauschild, M.Z., Shaked, S., Li, D.S., Gold, L.S. and Jolliet, O. (2011). USEtox human exposure and toxicity factors for comparative assessment of toxic emissions in life cycle analysis: sensitivity to key chemical properties. *The International Journal of Life Cycle Assessment* 16, 710-727. http://doi.org/10.1007/s11367-011-0316-4.

United States Environmental Protection Agency (2014). *Climate Change Adaptation Implementation Plan.* The Office of Chemical Safety and Pollution Prevention (OCSPP). https://19january2017snapshot.epa.gov/sites/production/files/2016-08/documents/ocspp-climate-change-adaptation-plan.pdf.

The Natural Step (2018). Bring strategic sustainability into your product design and innovation. https://thenaturalstep.org/slca. Accessed 1 January 2019.

Verones, F., Bare, J., Bulle, C., Frischknecht, R., Hauschild, M., Hellweg, S., Henderson, A., Jolliet, O., Laurent, A., Liao, X., Lindner, J.P., Maia de Souza, D., Michelsen, O., Patouillard, L., Pfister, S., Posthuma, L., Prado, V., Ridoutt, B., Rosenbaum, R.K., Sala, S., Ugaya, C., Vieira, M. and Fantke, P. (2017). LCIA framework and cross-cutting issues guidance within the UNEP-SETAC Life Cycle Initiative. *Journal of Cleaner Production* 161, 957-967. http://doi.org/10.1016/j.jclepro.2017.05.206.

# IV. Enabling policies and action to support innovative solutions

## About Part IV

Advancing a chemistry that is fully sustainable is dependent on scaling up innovative solutions; engaging new actors; and putting in place enabling policies. Innovative solutions complement long-standing measures to achieve the sound management of chemicals and waste, as discussed in Part III. They are an essential element in achieving the sound management of chemicals and waste. While the topics discussed in Part IV have been the subject of discussions and action taken at national and international level to varying degrees, they have by and large not received the attention warranted in the context of chemicals and waste. Opportunities therefore exist to explore their role in a beyond 2020 framework.

Relevant enabling policies and actions include education reform; support for technology innovation and financing; innovative business models; sustainable supply chain management; private sector metrics and reporting; fiscal incentives; and the empowerment of workers, consumers and citizens through information and participation rights. In exploring these topics, Part IV thus also draws attention to the contributions that can be made by a diverse range of actors, including entrepreneurs, academics, retailers, policymakers and citizens.

## Contents

1/ Envisioning and shaping the future of chemistry 504

2/ Green and sustainable chemistry education: nurturing a new generation of chemists 515

3/ Strengthening sustainable chemistry technology innovation and financing 524

4/ Evolving and new business models 542

5/ Fiscal incentives to advance sound chemicals management and sustainable chemistry 555

6/ Sustainable supply chain management for chemicals and waste in the life cycle 564

7/ Sustainability metrics and reporting: measuring progress, strengthening accountability 575

8/ Empowering and protecting citizens, workers and consumers 586

References 604

# 1/ Envisioning and shaping the future of chemistry

## Chapter Highlights

Innovations in chemistry, together with non-chemical alternatives, have significant potential to address societal needs and sustainable development challenges.

Sustainable chemistry is evolving as a holistic concept that embraces green chemistry, and that may serve as a reference for innovations in (or related to) chemistry.

The market for green and sustainable chemistry is growing in all regions, but is still modest compared to the overall chemistry market.

The Fourth Industrial Revolution, and digitalization of the chemical industry, provide opportunities to advance sustainability in the chemical industry.

A balance is needed between embracing the potential benefits of chemistry and recognizing challenges (e.g. the importance of addressing legacies).

## 1.1 Solutions shaped by chemistry are on the horizon

For more than a century the chemical industry has led innovations in areas including pharmaceuticals, plastics and consumer electronics that have transformed the way people live around the world. In particular, the period from the 1950s through the 1970s witnessed a wave of innovations in chemistry, with dozens of new chemicals and compounds discovered and commercialized. From 1980, however, new product development slowed down and few new blockbuster chemicals entered the market. During that time the global chemical industry focused on expanding to new markets, often selling chemicals invented long before such as polyvinyl chloride (PVC) (invented in 1913), polyethylene (1936) and polypropylene (1954). Return on investments from growth in new markets was more attractive than the return from innovation (Sarathy, Gotpagar and Morawietz 2017).

Today this situation is evolving. Lower profits from bulk chemicals, recent innovations in chemistry and advanced materials, and the challenge for the chemical industry to help meet the Sustainable Development Goals (SDGs) are creating new opportunities for chemistry to help meet society's needs. Examples are numerous and include the following:

- *Revolutionizing energy storage and battery development*: Fast-charging solid-state batteries, based on chemistry innovations, have the potential to revolutionize electric mobility. Not only can they be charged 10 times faster than traditional lithium-ion batteries, but they are safer as they cannot catch fire, are more reliable and are longer lasting.


© NASA/Dimitri Gerondidakis, a thin solid-state battery

- *Improving the biodegradability of bio-based plastics:* Biodegradable plastics, derived from agricultural or wood-based biomass, are compatible with home and municipal composting systems, have less environmental impact and can be incorporated into composting infrastructure. They can also form feedstocks for bioenergy and other circular economy applications.

- *Creating sustainable building materials:* Chemistry plays a key role in creating a new generation of sustainable and high-performing building materials. Examples include transparent wood, green concrete, wood foam insulation, and earthquake resistant bricks.

- *Turning carbon dioxide ($CO_2$) and wastes into chemical feedstocks:* Creating feedstocks that are not fossil fuel-based from $CO_2$ using renewable energy not only reduces greenhouse gas (GHG) emissions; it also advances circularity in the chemical industry by providing chemical feedstocks that are not derived from oil or bio-based materials.

- *Developing "advanced materials":* This involves developing materials and modifying existing ones to obtain superior performance in regard to one or more characteristics that are critical to the application under consideration, such as waterproofing textiles. These materials can also have completely novel properties, as seen, for example, in nanomaterials.

While such opportunities are promising, more thorough assessments are needed to obtain a full (or better) understanding of the sustainability aspects of these innovations, taking into account the criteria and tools discussed in Part III and in the remainder of this chapter.

Research across the disciplines of chemistry, biology and computer science is particularly promising. The 2018 Nobel Prize in Chemistry, for example, was awarded for path-breaking research on how chemists produce new enzymes, leading to new pharmaceuticals and cancer treatments and less waste. Another promising development is the use of advanced software and supercomputers to design molecules and assess the properties of chemicals, including their hazards. These developments have significant potential to advance the sound management of chemicals and waste, and to complement other measures in order to achieve sustainable production and consumption.

### Chemistry is at the core of future industry sectors

The contribution of chemistry to a range of end markets was presented in Part I. Some of these markets are of particular relevance to shaping the future of sustainable development – from the transportation industry, to the construction industry and urbanization, to food and packaging, to waste management. For example, the transportation and construction industries have a range of requirements that can be met through chemistry and sustainable materials innovations.

**Figure 1.1** Examples of how chemistry contributes to industries expected to play important roles in the future (adapted from World Economic Forum [WEF] 2017, p. 7)

| | | Projected growth rates for key innovations | Examples of relevant products from chemistry and advanced materials |
|---|---|---|---|
| **Mobility** | Electric vehicles | Annual sales of electric vehicles<br>2020: US dollars 4.9 million | Plastics, composites and battery technologies |
| | Drones | Market size for drones*<br>2015: US dollars 10.1 billion<br>2020: US dollars 14.9 billion | Plastics, composites and battery technologies |
| **Mobile and smart devices** | Smartphones and tablets | Mobile devices in use<br>2015: US dollars 8.6 billion<br>2020: US dollars $12.1 billion | Substrate, backplane, transparent conductor, barrier films and photoresists |
| | Flexible displays (e.g. wearable devices, virtual reality, TVs) | Market for AMOLED** displays<br>2016: US dollars 2 billion<br>2020: US dollars 18 billion | Substrate, backplane, transparent conductor, barrier films and photoresists |
| **Connectivity and computing** | High-speed internet | Fixed broadband speed<br>2015: 24.7 Mbps<br>2020: 47.7 Mbps | Chlorosilane for ultrapure glass |
| | More efficient and smaller integrated circuits | Processor logic gate length<br>2015: 14 mm<br>2020: 7 mm | Dielectrics, colloidal silica, photoresists, yield enhancers and edge bead removers |

* Defence, commercial and homeland security sectors ** Active-matrix organic LED

Figure 1.1 shows how chemistry contributes to industries which are expected to play key roles in the future.

### Innovations also include non-chemical alternatives

The concept of non-chemical alternatives is receiving wide attention, including by international policy bodies such as the United Nations Environment Assembly (UNEA), in research and innovation, in the private sector, and by non-governmental organizations (NGOs). Although a definition of the concept of non-chemical alternatives does not exist, the connotation is that innovations can often produce a desired function or benefits without an alternative synthetic chemical. For example, a retailer in Denmark launched a new fluorinated chemicals-free microwave oven popcorn bag made from cellulose that is impermeable to fat (Stieger 2015). The new product has become a commercial success. In the agriculture sector, the well-known concept of Integrated Pest Management (IPM) promotes a range of biological measures to eliminate or reduce the use of pesticides.

## 1.2 Green and sustainable chemistry: setting the standard

### Lessons learned from innovations in chemistry

Some chemistry innovations, acknowledged for their positive contributions to society, were recognized years later to have unexpected and undesirable effects when additional knowledge became available. For example, dichloro-diphenyl-trichloroethane (DDT) was synthesized in 1874 and its use spread around the world once its insecticidal action was discovered in 1939. DDT helps fight diseases such as malaria, yellow fever and West Nile virus. At the time it began to be used, however, little was known about its detrimental impact on human health and the environment. Similarly, chlorofluorocarbons (CFCs) enabled the use of refrigeration by large populations. It was only years later that their damaging impact on the ozone layer was understood. Again, when celluloid was invented to replace ivory billiard balls in the 19th century (inspiring the development of further petroleum-based plastic products), it would have been impossible to foresee the vast volumes of plastic that would be produced and eventually released to the environment.

## Green and sustainable chemistry as an evolving benchmark

As discussed in Parts II and III, knowledge, assessment tools and legislative instruments are available and used in many countries, albeit not globally, to ensure that new substances which may have adverse impacts on health and the environment do not reach the market. Furthermore, more detailed criteria are becoming available to assess the extent to which a chemistry innovation is fully compatible with the three pillars of sustainable development (economic, environmental and social). The concepts of green chemistry and sustainable chemistry provide promising guidance in this regard.

The term "green chemistry" was first used in the early 1990s. It gained momentum after it received support by the United States Environmental Protection Agency (US EPA) (Linthorst 2010). At the end of the 1990s Anastas and Warner defined green chemistry as "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacturing and application of chemical products" (Anastas and Warner 1998). They also proposed 12 Principles of Green Chemistry (Box 1.1). In a related development in Europe, similar principles were included in the Council Directive on integrated pollution prevention and control (European Commission [EC] 1996). Research related to green chemistry has made possible a wide range of developments in the fields of bio-based chemicals, renewable feedstocks, safer solvents and reagents, atom economy, green polymers, and less toxic chemical formulations (Anastas and Warner 1998; Philp, Ritchie and Allan 2013).

As a spin-off from work on green chemistry, a set of nine Principles of Green Engineering, now known as the Sandestin Declaration, were developed in 2003 (Abraham and Nguyen 2003). Green engineering goes beyond baseline engineering quality and safety specification to consider broader economic, environmental and social factors (Anastas and Zimmerman 2003). Other important developments compatible with green chemistry took place in the same period. They include the European Communities Chemistry

**Box 1.1** **The 12 Principles of Green Chemistry (Anastas and Warner 1998)**

1. *Prevention*: it is better to prevent waste than to treat or clean up waste after it has been created.

2. *Atom economy*: synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.

3. *Less hazardous chemical syntheses*: wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. *Designing safer chemicals*: chemical products should be designed to affect their desired function while minimizing their toxicity.

5. *Safer solvents and auxiliaries*: the use of auxiliary substances (e.g. solvents, separation agents) should be made unnecessary wherever possible and innocuous when used.

6. *Design for energy efficiency*: energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. if possible, synthetic methods should be conducted at ambient temperature and pressure.

7. *Use of renewable feedstocks*: a raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8. *Reduce derivatives*: unnecessary derivatisation (use of blocking groups, protection/de-protection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.

9. *Catalysis*: catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. *Design for degradation*: chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

11. *Real-time analysis for pollution prevention*: analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. *Inherently safer chemistry for accident prevention*: substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Council 1993 report on "Chemistry for a Clean World", conferences on the concept of Benign by Design (Linthorst 2010), and the development of related concepts such as cleaner processes, safer products, and the use of renewable feedstocks (Clark 2006; Mubofu 2016).

While the 12 Principles of Green Chemistry are widely used and cited, there is no agreement on how many of these principles must be fulfilled for a molecule or process to be qualified as "green" or how the different principles are to be weighed against each other (Zuin 2016). Therefore, a clear benchmark which determines whether a chemical is green does not exist. Despite these challenges, a number of accounts are available demonstrating how green chemistry has positively affected sustainability in several sectors (American Chemical Society [ACS] 2019; Erythropel *et al.* 2018).

### Towards a more holistic approach: sustainable chemistry

The notion of sustainable chemistry was also developed in the 1990s, with the Organisation for Economic Co-operation and Development (OECD) playing an important role in advancing this concept (OECD 2012). The OECD has defined sustainable chemistry as "a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services" (OECD 2018). According to this perspective, sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes. It also stimulates innovation across all sectors in order to design and discover new chemicals, production processes and product stewardship practices that provide increased performance and greater value, while meeting the goals of protecting and enhancing human health and the environment.

More recent discussions on sustainable chemistry have evolved beyond a focus on scientific and technical considerations towards a more holistic interpretation that takes into account the economic, environmental and social dimensions of sustainable development. For example, renewable feedstocks promoted by green chemistry may have sustainability trade-offs such as agricultural pollution. While sustainable chemistry embraces green chemistry principles, it covers broader considerations including (but not limited to) safe working conditions, human rights, ethics, new business and service models, and other related topics (Kümmerer 2017). Sustainable chemistry also emphasizes the role of chemistry in implementing the 2030 Agenda for Sustainable Development (Blum *et al*. 2017). A further development of the concept proposed by the German Environment Agency takes into account planetary boundaries (German Environment Agency 2016).

Based on a review of the literature and stakeholder interviews, a recent study by the United States Government Accountability Office (US GAO) on chemistry innovation "identified several common themes underlying what sustainable chemistry strives to achieve, including:

- to improve the efficiency with which natural resources [...] are used to meet human needs for chemical products, while avoiding environmental harm;
- reduce or eliminate the use or generation of hazardous substances [...];

**Figure 1.2** **Dimensions of a chemical enterprise: towards sustainability (adapted from Hill, Kumar and Verma 2013, p. 27)**

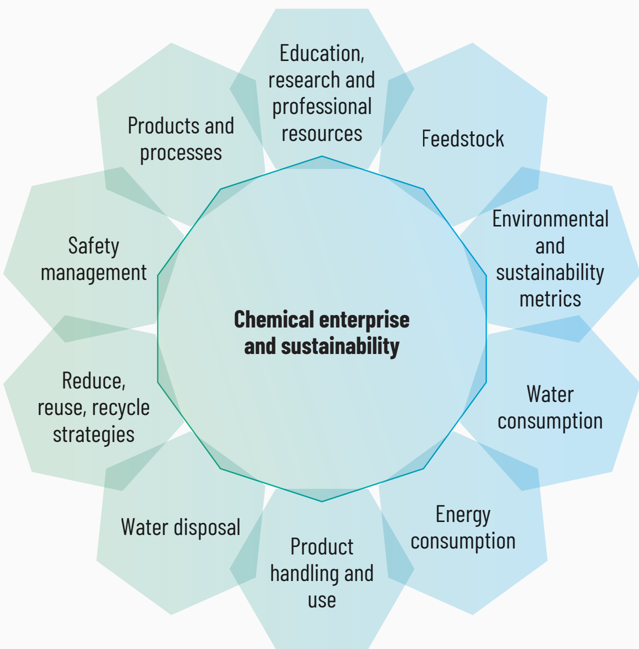
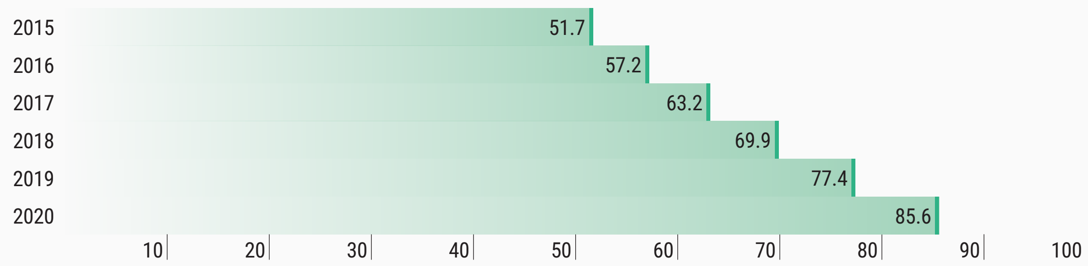


**Figure 1.3** Market size of the global green chemistry industry, 2015-2020 (US dollars billion) (based on BCC Research 2016)




- protect and benefit the economy, people and the environment using innovative chemical transformations;
- consider all life cycle stages, including manufacture, use and disposal [...] when evaluating the environmental impact of a product; and
- minimize the use of non-renewable resources" (US GAO 2018).

From a sustainability point of view, a chemical enterprise has many interconnected dimensions, each of which needs to be considered (Hill, Kumar and Verma 2013). Some of these dimensions are shown in Figure 1.2. An assessment of the sustainability of a chemical enterprise would cover a range of factors and all three dimensions of sustainable development. It might raise questions such as: under which circumstances could the use of biomass for chemicals and biofuel production be a viable alternative to the use of fossil sources, taking into account the potential economic, environmental and social consequences of its use? or, to what extent would the reduction of vehicles' $CO_2$ emissions through the use of composite materials outweigh the environmental impact of the production and/or future recycling of these materials?

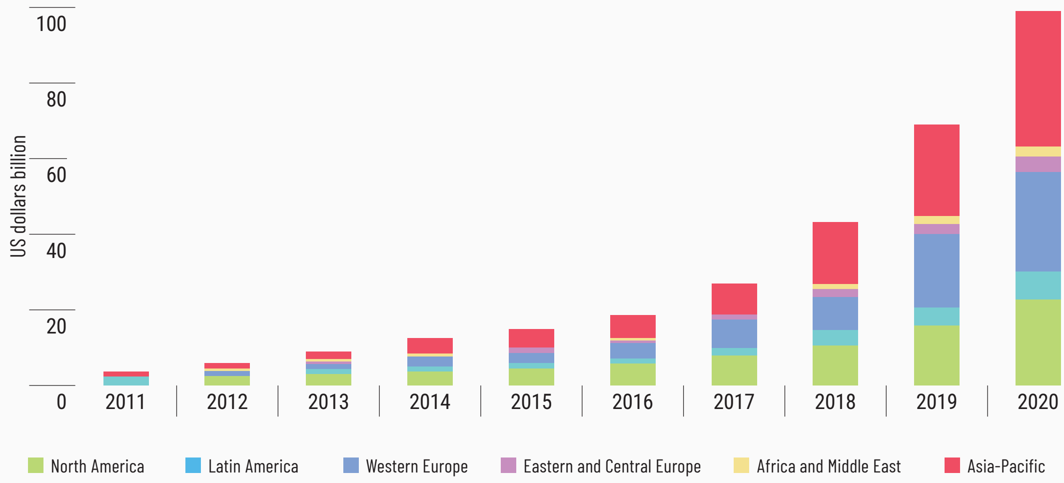
## The market potential for green and sustainable chemistry

While differences still exist in the characterization of green and sustainable chemistry, forecasts have been published which predict growing markets for green chemistry worldwide. The global green chemistry industry was reported to have a market value of more than US dollars 50 billion in 2015, with the potential to grow to US dollars 85 billion by 2020 (Figure 1.3) (BCC Research 2016). It has been estimated that the global market for green chemistry (including bio-based chemicals, renewable feedstocks, green polymers and less-toxic chemical formulations) will grow to nearly US dollars 100 billion by 2020 (Bernick 2016). While this amount is substantial, it is modest compared with total global chemical industry sales of some US dollars 5.7 trillion (see Part I, Ch. 1).

Green chemistry markets are expected to show growth in all regions, with Asia and the Pacific, Western Europe and North America the key market growth regions (Pike Research 2011) (Figure 1.4).

Forecasts suggest that the growth rate for green and safer chemistry products is considerably higher than that for conventional products (American Sustainable Business Council [ASBC] and Green Chemistry & Commerce Council [GC3] 2015). Tightening regulations, and growth in consumer demand for more sustainable products – along with the rising costs of fossil fuels – all contribute to this trend (BCC Research 2016). In light of these developments, many chemical companies see benefits in developing sustainable products such as healthier food and environmentally friendly detergents. Sustainable products thus provide companies with new avenues of growth and establish a stronger connection with millennials, who are driving demand for these products (Bhattacharjee and Swamynathan 2017).

**Figure 1.4** Global green chemicals market by region (US dollars billion), 2011-2020 (Pike Research 2011, p. 432)






### International developments: towards a common understanding of sustainable chemistry

In 2016, at the second session of the UNEA, in Resolution 2/7 Governments recognized the concept of sustainable chemistry and initiated further work by the United Nations Environment Programme (UNEP), including the development of a report on how best practice in sustainable chemistry could help achieve the SDGs. Sustainable chemistry has also been among the topics discussed under the intersessional process on the Strategic Approach to International Chemicals Management (SAICM) and the sound management of chemicals and waste beyond 2020.

The 2019 report prepared by UNEP in response to that UNEA mandate notes the wide use of the sustainable chemistry concept by various stakeholders around the world (UNEP 2019). However, taking into account an analysis of submissions of sustainable chemistry cases by stakeholders, and the results of a survey of SAICM stakeholders, the report also notes that a common understanding of the sustainable chemistry concept does not exist at the global level. For example, one open question is the extent to which non-chemical alternatives are within the scope of sustainable chemistry. Given the interest of a number of stakeholders (including many from developing countries) in understanding and developing the sustainable chemistry concept further, the report suggests that practical guidance on sustainable chemistry be developed. Such guidance could be complemented by, or include, a simple definition of sustainable chemistry or a more elaborate definition if that is considered valuable. Such work might also further develop the compatibility of, and the relationship between, the green and sustainable chemistry concepts explored already, for example by Sheldon (2008), Kümmerer (2017) and Anastas and Zimmerman (2018). Together these concepts could be widely promoted, inspiring research, policymaking and private sector action compatible with, and in support of, the 2030 Sustainable Development Agenda.

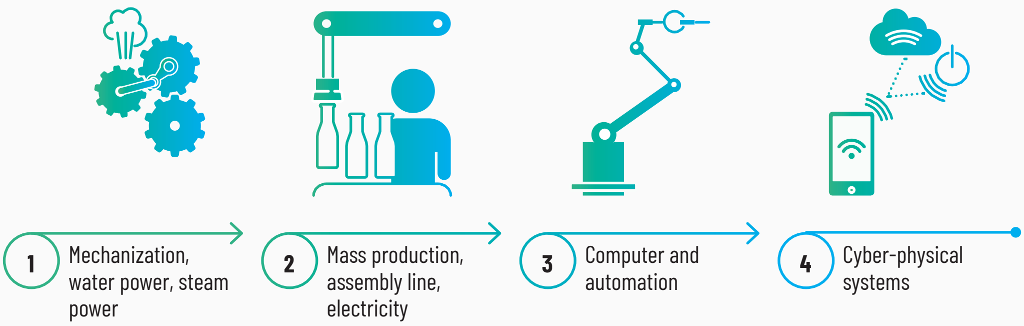
## 1.3 Digitalization and the chemical industry: opportunities to advance sustainability

While in the past there was a focus on the invention of new molecules, future innovations in chemistry will likely be based on integrated solutions which are based on digital technologies.


Industry 4.0 (Cisco 2017; EC 2017) and digitalization will impact a range of (if not all) aspects of the chemical industry: how it innovates and produces; how it conducts businesses and engages with actors across supply and value chains; and its productivity and safety.

Chemical manufacturing operations, in particular, are one of the largest and most readily accessible areas of opportunity for digitalization, from petrochemicals to pesticides. Most chemical plants continuously generate an enormous amount of data, but discard most of them. Managers could collect these data and interpret them in order to find ways to achieve higher yields and throughput, lower energy consumption, reduce pollution and foster effective maintenance. For many companies these are potentially easy wins that could be achieved using existing information technology (IT) and process control systems.

**Figure 1.5** **The four industrial revolutions (adapted from Cisco 2017)**



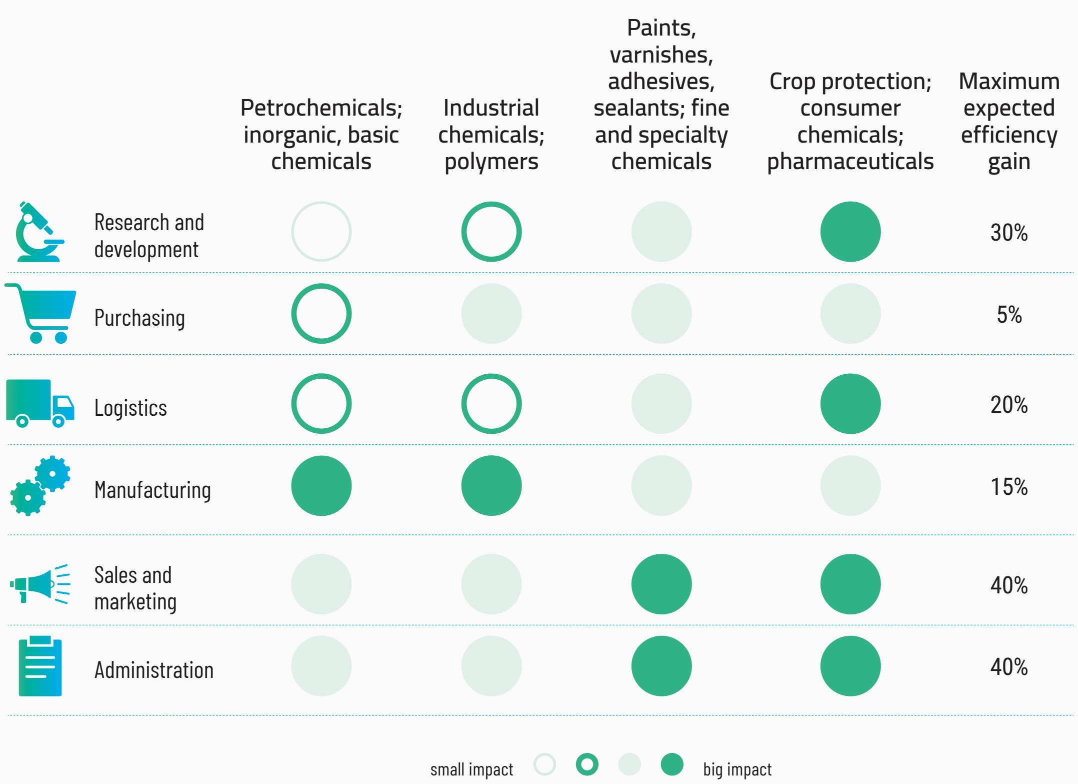

The Fourth Industrial Revolution refers to a new era in the interface of industrial production, digitalization and society which impacts a range of aspects of the chemical industry: how it innovates and produces; how it conducts business; how it engages with actors across supply and value chains; and its productivity and safety. While in the past there was a focus on the invention of new molecules, future innovations in chemistry, chemical safety and resource efficiency will likely be based on integrated solutions that are based on digital technologies. At the same time, digitization may also be associated with risks such as possible cyberattacks.

New integrated technologies are also on the rise. For example, drones and robots have started to play an important role in agriculture to minimize pesticides application, using global positioning system (GPS)-based systems.

While the chemical industry, according to a McKinsey & Company study (Jakobsen *et al.* 2017), has been perceived to lag behind in digitalization, the potential economic benefits are enormous. During the next decade or so, the digitalization of operations and commercial functions in the chemical industry has the potential for value creation of 4 to 6 per cent (Jakobsen *et al.* 2017). There is potential for companies to achieve a 3 to 5 percentage point improvement in sales through employing digitalization in production operations (Klei *et al.* 2017). This could unlock up to US dollars 550 billion (WEF 2017) in value in the next decades. Other important and related benefits include lower GHG emissions, reduced accident and injury rates, and greater value chain transparency (Cayuela and Hagan 2019).

Advanced analytics, the internet of things, and artificial intelligence can combine information from millions of sensors to boost not only operational productivity, but also energy efficiency, emissions reductions, and environmental and safety performance. For example, using drones and robots for certain operations could lower injury levels. Ultimately, the use of automation across processes and supply chains reduces manual interventions and paper-based documentation, thereby accelerating productivity and safety. Digitalization also enables more rapid experimentation, the discovery of new materials at lower cost, and better understanding of chemicals' hazardous properties (Figure 1.6). This means eventually exploring the enormous, and currently unexplored, chemical space (Kirkpatrick and Ellis 2004) of over $10^{60}$ conceivable compounds and filtering it to a manageable number that can be synthesized, tested and assessed for meeting sustainability criteria.

**Figure 1.6** **Overview of the implications of digitalization in the chemical industry (adapted from Deloitte and German Chemical Industry Association 2017, p. 14)**



### Considering potential trade-offs

While the opportunities of Industry 4.0 and digitalization for the chemical industry are significant, pervasive and will be long-lasting, there are also challenges. These include, for example, cybersecurity, possible data misuse and cybercrimes, as well as accountability challenges associated with decentralized production and markets. Digitalization will also require resources, such as energy or metals for hardware. Ultimately, however, Industry 4.0 and digitalization are here to stay. They will change the shape of the chemical industry from the current interplay of energy, materials, molecules and atoms to an interplay more focused on atoms and bits (Cayuela and Hagan 2019).

## 1.4 Enabling the potential of sustainable chemistry innovation

Advances in chemistry are occurring in the real world. They will continue to be one of the bases on which societies and economies are built. Chemical substances and materials, and their properties, actions and performance, will be at the heart of the processes and products that define our future. Innovation in chemistry (particularly in the fields of biotechnologies, advanced materials, nanotechnologies, energy and environment), and the growing global market for sustainable goods and services, are shaping the future of the chemical industry and creating new investment opportunities. The industry is in a position to help other sectors achieve their most ambitious objectives, from food to energy to resource security. Some leaders have already emerged in these sectors. They see this potential, and are ready and committed to help address sustainability challenges with and through chemistry.

The direction in which chemistry develops will depend on new leadership approaches in industry, and on how societies can work collaboratively with the chemical industry to support its transformation to sustainability. As the industry is subject to public scrutiny and demands for transparency and responsibility, educating and engaging with the public and all others to discuss the risks and benefits of the chemical industry and its opportunities for sustainability will be of value. New metrics for innovation, sustainability and accountability are needed, as well as programmes to mobilize scientific talent to embrace green and sustainable chemistry and scale up innovation. Furthermore, an ethical, value-driven approach to technological progress in the chemical industry is essential. For all this to occur, it will be paramount to find a balance in creating a discourse around the opportunities provided by chemistry – while not ignoring its risks. Finding such a balance will help to address the legacies of the past, as well as sustainability, and to mobilize the best and brightest minds in science to reap potential rewards. The following chapters in Part IV address these and related opportunities to scale up innovative solutions.

# 2/ Green and sustainable chemistry education: nurturing a new generation of chemists

## Chapter Highlights

Green and sustainable chemistry education (GSCE) is gaining momentum through its integration into relevant curricula, scientific journals and academic conferences.

Despite significant advances in mainstreaming GSCE, major gaps remain in all regions.

Institutions and networks are developing an increasing number of relevant tools and materials for use at the primary, secondary, tertiary and professional levels.

While green and sustainable chemistry is taught selectively in countries across all regions, there is potential to scale up efforts, particularly in developing countries.

Barriers to reform exist. They include professional and institutional resistance, and a lack of awareness.

Mainstreaming GSCE in curricula at all levels includes disseminating best practices, utilizing existing networks, and strengthening partnerships.

## 2.1 A new way to teach chemistry

### From chemistry to green chemistry, and green and sustainable chemistry education

Historically, toxicology and concerns about the protection of human health and the environment have received limited attention in chemistry classrooms. However, a paradigm shift towards pollution prevention took place in the second half of the 20$^{th}$ century, accompanied by growing awareness of the adverse effects of certain chemicals, as also reflected in regulatory action taken. A major milestone that can be seen as having accelerated the momentum towards green chemistry is the Pollution Prevention Act adopted in the United States (US) in 1990, which stated that "pollution should be prevented or reduced at the source whenever feasible" (US EPA 2017).

Chemistry education has reflected this conceptual transition during the last 20 years, and curricula in many countries have been revisited (Anastas 2015; Clark 2016). In 1997 a doctoral programme on green chemistry was introduced at a university for the first time. The early 2000s saw a proliferation of these new ideas, mainly under the label of "green chemistry", in the scientific community (particularly in the United States) (Cohn 2012). This was demonstrated, for example, by the Green Chemistry Institute becoming part of the ACS (ACS 2019a). Subsequently a growing number of universities incorporated

**Table 2.1 Sustainable chemistry teaching: laboratory content (adapted from Aubrecht *et al.* 2015, p. 632)**

| Theme | Laboratory topic | Primary chemistry concepts | Connections to sustainability |
|---|---|---|---|
| Environmental degradation | Interaction of acid rain with minerals | Titrations, neutralization reactions, metal ion solubility | Sources and impacts of acid rain, ocean acidification, mitigation efforts |
| Energy production | Preparation and use of dye-sensitized solar cells | Semiconductors, doping, silicon and dye-sensitized photovoltaic cells | Solar energy, stabilization wedges approach to reduce greenhouse gas emissions |
| Green chemistry | Synthesis of a biodegradable polymer and recycling of polyethylene terephthalate (PETE) | Polymers, line-angle functional groups, infrared (IR) spectroscopy | Renewable feedstocks, biodegradability, "cradle to cradle" design, green chemistry |

Aubrecht *et al.* (2015) described the content of a series of day-long field trips by high school students to a university where chemistry content was connected with sustainability issues. Experiments focused on environmental degradation, energy production and green chemistry.

green chemistry in their curricula, mainly for organic synthesis, and gradually incorporated the 12 Principles of Green Chemistry (ACS 2019b) in regular chemistry courses. Despite these advances, the number of schools and universities that have integrated green and sustainable chemistry in relevant curricula remains limited.

Today some elements of green chemistry education have been solidly established in many universities and are being promoted by companies, governments and NGOs worldwide. The expansion of the 12 Principles to wider dimensions with the label "sustainable chemistry education" in university and other curricula is a more recent phenomenon (Kümmerer 2017). While an increasing number of academic institutions have now embraced the concept of green chemistry, the concept of sustainable chemistry has been introduced less frequently (e.g. at the Leuphana University of Lüneburg in Germany). Thus there is still significant potential and need to further mainstream green and sustainable chemistry education (GSCE).

### Green and sustainable chemistry education can be introduced in a wide range of institutions and curricula

The concepts and principles of GSCE can feed into education at various levels and in different settings, including high schools, universities and professional education. GSCE has been introduced at an increasing number of research institutions and universities. Various institutions have also developed tools and materials to allow the integration of green and sustainable chemistry at high school and even elementary levels (e.g. ACS 2019a; Beyond Benign 2019) in order to adequately address toxicology in the classroom (Cannon *et al.* 2017). For example, in the context of the United Nations Educational, Scientific and Cultural Organization (UNESCO) World Decade of Education for Sustainable Development (ESD) (2005-2014) learning materials for secondary education and universities were developed that addressed topics related to green and sustainable chemistry (Burmeister and Eilks 2012; UNESCO 2014; Zuin and Mammino 2015). There is hope that this development will continue in the framework of the Global Action Programme on Education for Sustainable Development, which is the follow-up programme to the Decade of ESD (UNESCO 2018).

Eissen *et al.* (2008) reported the development of a new lab course for higher organic chemistry education. Aspects of the efficiency and sustainability of reactions, as well as toxicological and ecotoxicological knowledge, were added to the teaching content. Students were encouraged to plan, set up and reflect on organic laboratory activities, while taking into account any effects on people and the environment.

## 2.2 Education reform is gaining momentum, but significant gaps remain across regions


The extent to which GSCE has reached the general public, or has had a large-scale impact on behaviour patterns, is still limited (Mammino 2015; Beyond Benign 2019). Similarly, the inclusion of green and sustainable chemistry in university curricula has in many cases been confined to events, summer schools, short courses, one-off activities, and the inclusion of specific elements of GSCE in existing courses (Leitner 2004; Collins 2017).

There has been momentum in recent years to mainstream GSCE in academia. International conferences are also being organized on a regular basis, including in developing countries. Examples include the International Union of Pure and Applied Chemistry's (IUPAC) annual International Conference on Green Chemistry, the Annual Green Chemistry & Engineering Conference, the International Conference [on] Green and Sustainable Chemistry (the global green chemistry community); Elsevier's and Leuphana University's Green and Sustainable Chemistry Conference; and the Asia-Oceania Conference on Green and Sustainable Chemistry. Yet major international chemistry education conferences only incorporate green chemistry to a limited extent.

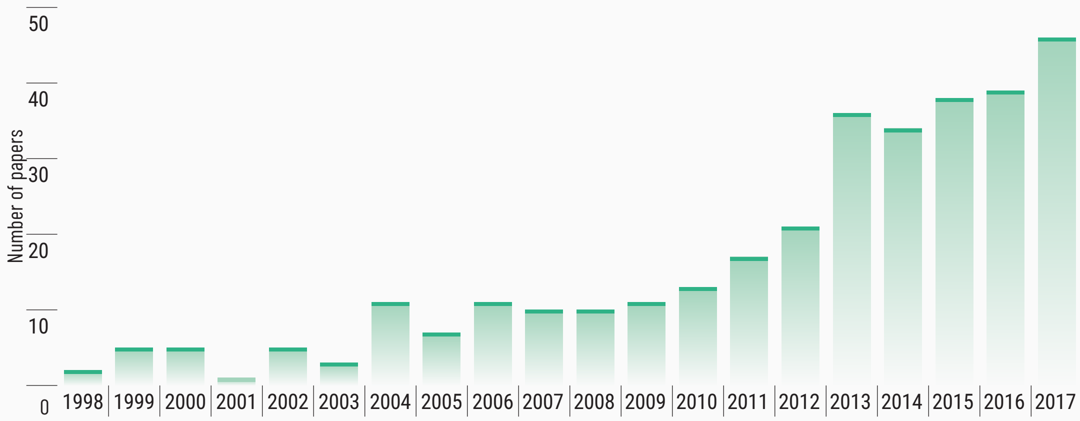
A growing number of academic journals focus on green and sustainable chemistry, including the Royal Society of Chemistry's (RSC) *Green Chemistry*, the ACS's *Sustainable Chemistry and Engineering*, VCH-Wiley´s *ChemSusChem,* and Elsevier's *Sustainable Chemistry and Pharmacy* and *Current Opinion in Green and Sustainable Chemistry*.

In a number of countries the concept of green – more than sustainable – chemistry has also

**Box 2.1 Examples of universities offering courses in green and sustainable chemistry**

City University of Hong Kong (China)
Federal University of Rio de Janeiro (Brazil)
Federal University of São Carlos (Brazil)
Fudan University (China)
Ghent University (Belgium)
King's University College (Canada)
Lomonosov Moscow State University (Russia)
McGill University (Canada)
Mendeleyev University of Chemical Technology (Russia)
Monash University (Australia)
Nankai University (China)
National University of La Plata (Argentina)
Queen´s University (Canada)
Queen´s University (UK)
Universidad Autónoma de Nuevo León (Mexico)
Universidad de Cordoba (Spain)
Universities of Porto and NOVA Lisbon (Portugal)
University of Amsterdam (The Netherlands)
University of Bath (UK)
University of Cape Town (South Africa)
University of Delhi (India)
University of Dodoma (Tanzania)
University of Massachusetts, Lowell (US)
University of Nottingham (UK)
University of Oregon (US)
University of Toronto (Canada)
University of Valencia (Spain)
University of Venice (Italy)
University of York (UK)
Yale University (US)

**Figure 2.1** **Number of papers published on GSCE, 1998-July 2018, concerning green chemistry education or sustainable chemistry education (adapted from Clarivate 2018)**

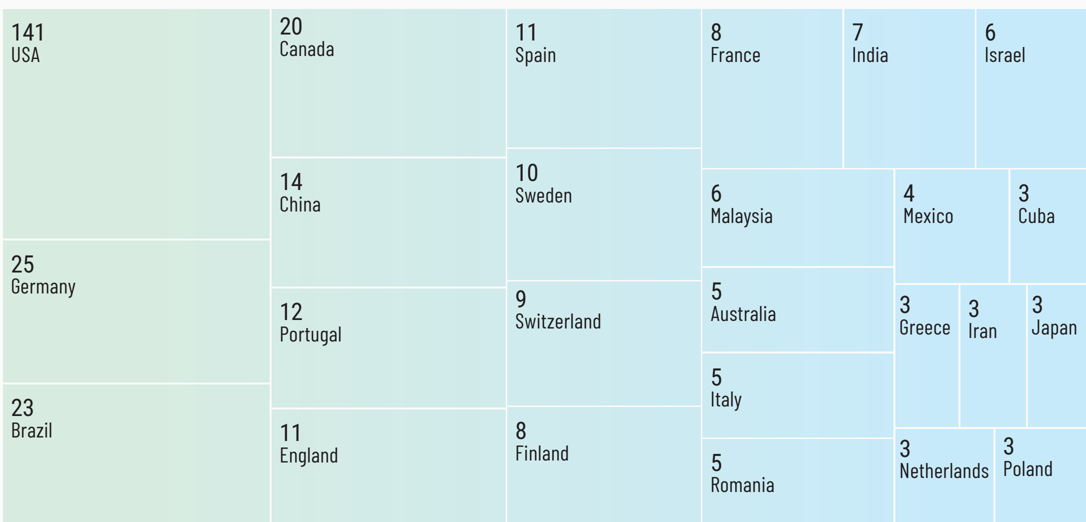





been integrated in university curricula in the form of research programmes, courses and master's programmes. Universities offering courses in green chemistry include those listed in Box 2.1. Some of these courses are undertaken in partnership with the private sector. Green chemistry is also taught in regular courses. Based on an initiative of the German Federal Environmental Foundation, an entire laboratory course was developed to teach organic chemistry practically, based on ideas of green and sustainable chemistry. Today this course is available in more than 10 languages, including English, Spanish and Russian (Network Operations Portal 2018).

Most such initiatives have been taken in developed countries (Gross 2013; Juntunen and Aksela 2014; Kennedy 2016), although gaps remain (Kitchens *et al.* 2006; Hamidah *et al*. 2017). Yet an increasing

**Figure 2.2** **Number of papers published on GSCE, 1998-July 2018 (adapted from Clarivate 2018)**



number are emerging in developing countries and countries with economies in transition in all regions. Green and sustainable chemistry education appears to be gaining momentum in China, in particular (Wang, Li and He 2018). An analysis found that more than 1,200 papers published in the journal *Green Chemistry* between 1999 and 2016 originated in China (Shuang and Yanqi 2018). The Indian Ministry of Education is piloting a programme in which all chemists will take a one-year course in green chemistry.

The number of papers addressing GSCE has grown in recent years. More than 300 papers are available in the literature from 1998. Most address the development of curricular materials; the assessment of student learning, and attitudinal outcomes from these curricula; and the use of multidimensional green chemistry metrics integrating broader societal factors and new pedagogical approaches. A significant share of these papers were published by scholars from developing countries or those with economies in transition, such as Brazil, China, India, Malaysia and Mexico (Figure 2.1 and Figure 2.2).

### Diverse approaches and ongoing reforms

Depending on the institutional context, green and sustainable chemistry has been taught differently, with diverse approaches, materials and focuses (Box 2.2). Specific initiatives have also had an impact on behavioural patterns in a variety of communities (e.g. progressive greening of universities, companies and informal educational institutions) (Mammino 2015).

A variety of educational materials have been developed to convey the principles of green and sustainable chemistry in school chemistry education and academia (Eilks and Rauch 2012; Levy and Middlecamp 2015; Zuin and Mammino 2015; Welton *et al.* 2018). In view of the increasing attention being given to all three dimensions of sustainable development (economic, social and environmental), academics have responded by adjusting course content and materials to adequately consider the societal factors of sustainability (Burmeister and Eilks 2012; Armstrong *et al.* 2018). The case has been made for reconceptualizing GSCE through adjusting curricula and methodologies to "foster eco-reflexive chemical thinking and action" (Sjöström, Eilks and Zuin 2016; Sjöström and Talanquer 2018). Integrating this dimension could enable individuals to respond to complex challenges, in line with the principles of sustainable development (Figure 2.3).

In recent years momentum has been growing in the chemistry community to incorporate systems thinking. A number of authors have underlined this need, stressing the opportunities it would offer by empowering chemistry students to innovate for a sustainable future (Mahaffy *et al.* 2018). The IUPAC, which has a project on integrating systems thinking into chemistry education, notes that such an approach "draws

**Box 2.2 Green chemistry and sustainability in professional education and training courses: a case study from Brazil**

The National Service of Industrial Training, organized and run by industrial entrepreneurs through the National Confederation of Industry and state federations, was created to train qualified workers for Brazilian industry. Together with the Ministry of External Relations, it operates in Cape Verde, Guinea-Bissau, Guatemala, Paraguay, East Timor, Mozambique, Peru, Jamaica, and São Tomé and Príncipe. In 2015 the SENAI Green Chemistry Institute Brazil was launched. It is committed to increasing general global awareness and capacities for deployable green chemistry approaches, aiming at product design and processes that will have global environmental benefits throughout their life cycles. Under the umbrella of the UN Industrial Development Organization's (UNIDO) Green Chemistry Initiative, a pilot project will demonstrate that green chemistry works for applications on a large scale in the area of bio-based plastics production in Brazil. Other studies will look at advancing green chemistry and green engineering technology applications in developing countries and those with economies in transition (UNIDO 2018).


attention to a need to balance the benefits and impacts of chemical substances and the role they play in societal and environmental systems" (IUPAC 2018). Incorporating systems thinking in chemistry curricula would thus encourage students to use chemistry as a tool to find solutions for global challenges.

### Chemical societies and green and sustainable chemistry education networks are advancing the integration of green and sustainable chemistry in curricula

Strengthening transnational, collective and multi-sectoral efforts towards a common agenda for

**Figure 2.3** **Steps to promote GSCE (adapted from Armstrong *et al.* 2018, p. 62 and Sjöström and Talanquer 2018)**

GSCE – promoted by adequate pedagogical approaches – requires the engagement of existing networks, putting together champions and innovators in the field (Collins 2001; International Sustainable Chemistry Collaborative Centre [ISC3] 2018; Yale University n.d.). Strategic partnerships and the creation of networks of educators have been identified as key determinants of success (Haack and Hutchison 2016; Zuin 2016).

A number of national, regional and global networks have been established to advance the mainstreaming of GSCE in developed and developing countries, such as the Global Network of Chemistry Centres (2016) and the GC3 (n.d.). The GC3 has a long-running project to embed green chemistry in academic and professional education. It has also published a Policy Statement on Green Chemistry in Higher Education, featuring (among others) a commitment to advance green chemistry education and research across disciplines.

Many national chemical societies have founded sections, committees or networks for green or sustainable chemistry, including the German Chemical Society (GDCh), the RSC and the ACS, which is also implementing a Green Chemistry Education Roadmap seeking to address prevailing gaps in integrating green chemistry in relevant curricula (ACS 2019c). In 2017 the IUPAC formed an Interdivisional Committee on Green chemistry for sustainable development (Italian National Committee for IUPAC of the National Research Council of Italy 2016).

## 2.3 Overcoming barriers: key determinants of effective educational reform

### Implementing green and sustainable chemistry education in developing countries

Making current chemistry practice green and sustainable is a relatively new concept in some countries, but one which is especially important to developing countries. The current curricula for the education of chemists and engineers in those countries barely considers environmental sustainability as a component. This makes it difficult to develop a consciousness of the implications of synthetizing chemicals with multiple applications, while also considering the life cycle of chemicals and their final fate in the environment (Barra and González 2018).

Currently a number of countries face several challenges regarding the design and implementation of GSCE, among which is a lack of scientists considering corresponding approaches. This is a barrier to awareness-raising by new professionals and scientists sensitized to addressing the issue. The language barrier with respect to the international literature might be a further hurdle for implementation of GSCE in certain countries. To date, few universities are proactively addressing the issue. Current curricula for chemists and engineers in many universities provide limited room for green chemistry principles and practices or sustainability issues. For example, there is a need to strengthen education in chemical synthesis and green chemistry principles to address molecular design and minimize impacts *ab initio* (i.e. starting from the beginning), in addition to a pursuit of material innovation including online pedagogical platforms and virtual activities (Haley *et al.* 2018).

### Educating a new generation of chemists for the private sector

Embedding green and sustainable chemistry in academic and professional education across supply chains can contribute to building communities with a strong understanding of the chemistry, product design and sustainability nexus. Many initiatives prioritize the education of teachers and lecturers, as they can influence the knowledge and opinions of present and future generations (Karpudewan, Ismail and Roth 2012; Beyond Benign 2019; GC3 n.d.).

Mainstreaming GSCE not only into chemistry and engineering departments, but also into business and law schools, public administration and companies will be critical given these stakeholders' role in establishing, assessing and implementing technological, economic, financial and fiscal activities and policies (Box 2.3). Some

**Box 2.3** **The CHEM21 online learning platform (CHEM21 n.d.)**

Regarding continuing professional development, the CHEM21 (n.d.) online platform established by the EU IMI CHEM21 project (Chemical Manufacturing Methods for the 21st Century Chemical Industries) was designed to provide a broad range of free, shareable and interactive educational and training materials to promote the uptake of green and sustainable methodologies in the synthesis of pharmaceuticals. Interactive elements include multiple choice quizzes with instant feedback, and downloadable problem-solving exercises (which can be carried out individually, or in groups, in a workshop setting) to encourage critical thinking on topics such as metrics, solvent selection and process safety (Summerton, Hurst and Clark 2018).


professional education programmes geared towards green management have been described, demonstrating that employees' attitudes to green management approaches became more positive and motivated through participating in new green management activities (including education programmes for other partners) (Lee 2009; University of Oregon 2018).

## Overcoming professional and institutional resistance

The barriers to successful implementation of GSCE are significant and are quite similar globally. Lack of cultural and institutional openness to change, or professional conservatism, have been identified as critical obstacles (Vallée 2016). According to Matus *et al.* (2012), corroborated by recent research conducted with leaders in several sectors worldwide, a complex set of interconnected issues act as barriers to the effective implementation of GSCE and wider sustainability considerations. Most of these fall into the categories of inertia and resistance related to organizational and cultural change; insufficient financial, social and economic support; and lack of knowledge about green and sustainable chemistry among staff. Another challenge identified in the literature is the absence of the use of harmonized and clear definitions and metrics by academia and decision-makers (Matus *et al.* 2012).

Despite these challenges, a number of opportunities exist. Several stakeholders, including industry, academia, NGOs and policymakers, can make an important contribution by facilitating a shift in focus towards the design and use of safer chemicals and sustainable production processes. A number of local case studies have demonstrated the successful integration of green and sustainable chemistry, including in the private sector. In addition, a number of strategies, including distance learning with both blended and face-to-face approaches, have shown that there are a range of opportunities to overcome identified gaps, including transdisciplinary research and teaching, Industry 4.0 and big data systems (Zuin and Mammino 2015; Ellen MacArthur Foundation 2017). Moreover, tools have been developed to assist universities in assessing how well their curricula address sustainable development, as a means of identifying opportunities to capture sustainability issues in a more strategic manner (Lozano and Watson 2013). Holme and Hutchison (2018) describe the establishment of an overarching learning outcome for chemistry courses, noting that both the benefits and hazards of chemicals could trigger change.

### The need to bring together policymakers, scientists and the private sector

Public support for green and sustainable chemistry requires a broader societal education in which stakeholders should be considered, including chemical producers, entrepreneurs, environmental justice groups, NGOs, downstream businesses, consumers, workers and professional associations. While motivated educators are necessary for the process of curriculum greening, they are not sufficient. It has been observed that this process can be significantly influenced by other constituents which can support them, providing resources such as educational materials and case studies (Centi and Perathoner 2009; Vallée 2016). For example, the ACS has been identifying tools to support work carried out in teaching laboratories, additional curricular materials for teachers, local government resources, and links to online networks, essentially for the United States (ACS 2019c). More recently, a new initiative to screen, assess, develop and apply international study programmes for sustainable chemistry education has been launched: the ISC3-Research Hub aims to offer scientific courses on a global level involving, for example, universities and public authorities, especially in developing countries and countries with economies in transition, in order to promote correlated programmes in their institutions (ISC3 2018).

## 2.4 Potential measures to scale up green and sustainable chemistry education

Building on existing initiatives, further efforts are needed at all levels to mainstream green and sustainable chemistry education into chemistry and other education curricula and teaching, including gathering and disseminating best practices and forging new and strengthened partnerships. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance green and sustainable chemistry education:

- Develop appropriate local and global programmes for GSCE, and define fundamental pedagogical content, objectives, methods and evaluation processes.
- Gather and disseminate best practices for integrating GSCE in chemistry and other curricula at secondary, higher (university) and technical educational levels.
- Scale up the training on GSCE of teachers and lecturers across all educational levels.
- Enhance funding and cooperation, including through existing GSC networks, to further promote and implement GSCE in developed, developing and transition economies.
- Embed GSCE as a critical element of wider education reform, including through strategic collaboration with programmes such as the UNESCO Education for Sustainable Development initiatives.
- Engage stakeholders from all sectors in the development and implementation of effective strategies for GCSE, in order to prepare students to address global sustainability challenges.
- Further mainstream GSCE in professional education, including through public-private partnerships.
- Further advance a common understanding of green and sustainable chemistry concepts, including in the context of education.

# 3/ Strengthening sustainable chemistry technology innovation and financing

## Chapter Highlights

Opportunities exist to scale up problem-solving oriented research and innovation in chemistry and related disciplines to support implementation of the 2030 Agenda for Sustainable Development.

Public research agendas, funding, and catalysing of support play important roles during early stages of the innovation process, as does private sector support.

To achieve the potential of chemistry start-ups to accelerate green and sustainable chemistry innovation, effective support mechanisms and innovative funding are important.

Engaging the financial services industry is important, but so far this source has not been fully tapped.

Collaborative innovation promises to focus research on problem solving by bringing together research institutions, the private sector, government and civil society.

An effective enabling environment for collaboration, including policies and incentives that nurture and do not stifle innovation, improves chances for successful outcomes.

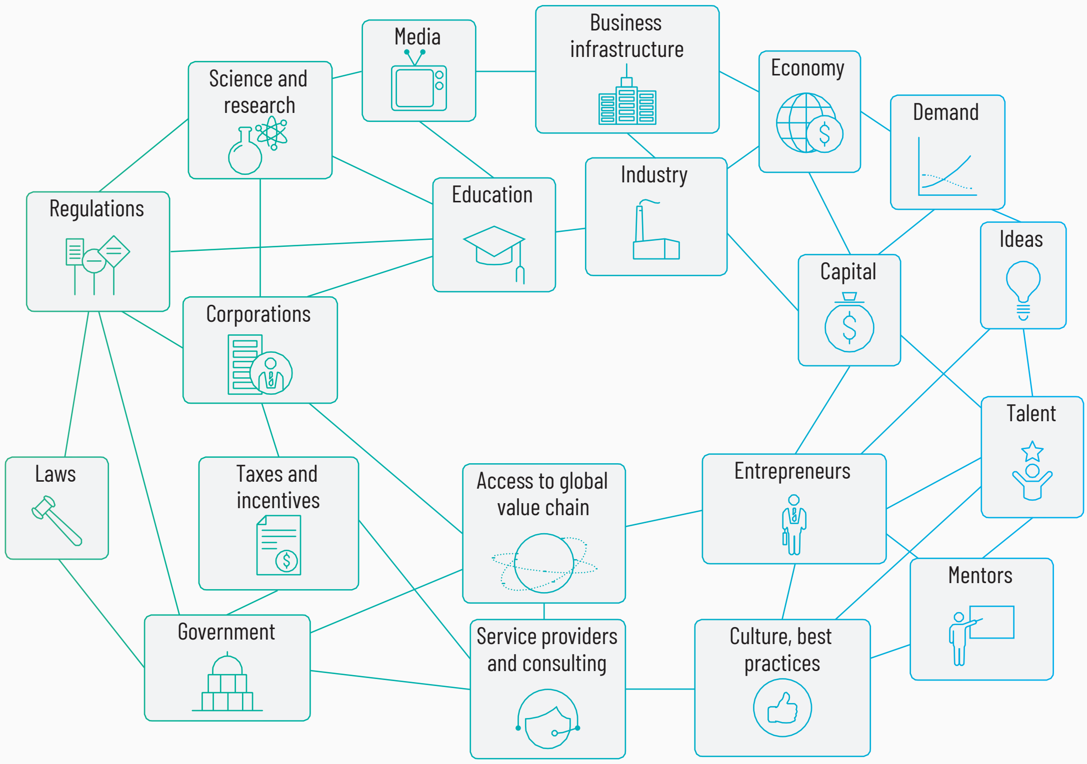
Significant opportunities exist for innovation in chemistry to help achieve the development goals and targets in the 2030 Agenda for Sustainable Development. The problems are diverse and challenging. To address climate change, energy supply and resource scarcity, for example, the functionality of chemicals and new materials is crucial. Yet chemistry innovation is complex and requires considerable resources and technical infrastructure, often more so than in other sectors such as IT. Laboratory equipment is costly, as are staffing, safety measures, waste treatment and other infrastructure needs. In the previous chapter the essential role of science and chemistry education was underlined. But what else is needed to drive innovation?

## 3.1 Opportunities and challenges in strengthening sustainable chemistry innovation

### From basic research to research that solves societal challenges

Future research in chemistry, if undertaken to meet societal challenges, needs to be directed specifically towards that goal. This type of research may be fostered through the development research agendas of public and private actors, ideally together, that support implementation of the 2030 Agenda for Sustainable Development. The European Technology Platform for Sustainable Chemistry

**Figure 3.1** Innovation ecosystem model (adapted from Ryzhonkov 2013)




(SusChem), for example, is a forum which brings together industry, academia, policymakers and wider society to establish research priorities directly linked to the 2030 Agenda (SusChem 2017).

There are many examples of innovations in chemistry that have not led to green and sustainable products. It is thus important for the actors engaged in research and innovation to take into account the guiding principles associated with green and sustainable chemistry and life cycle thinking. For example, start-up incubators and accelerators and funding mechanisms may integrate sustainability criteria in their selection process, in addition to economic viability criteria, especially if research is co-financed by public entities. In this context all actors concerned can benefit from interacting with end users and communities before developing start-ups that seek social use of new technologies or products, especially in sectors such as agriculture or sustainable mining.

## The ecosystem for sustainable chemistry research and innovation

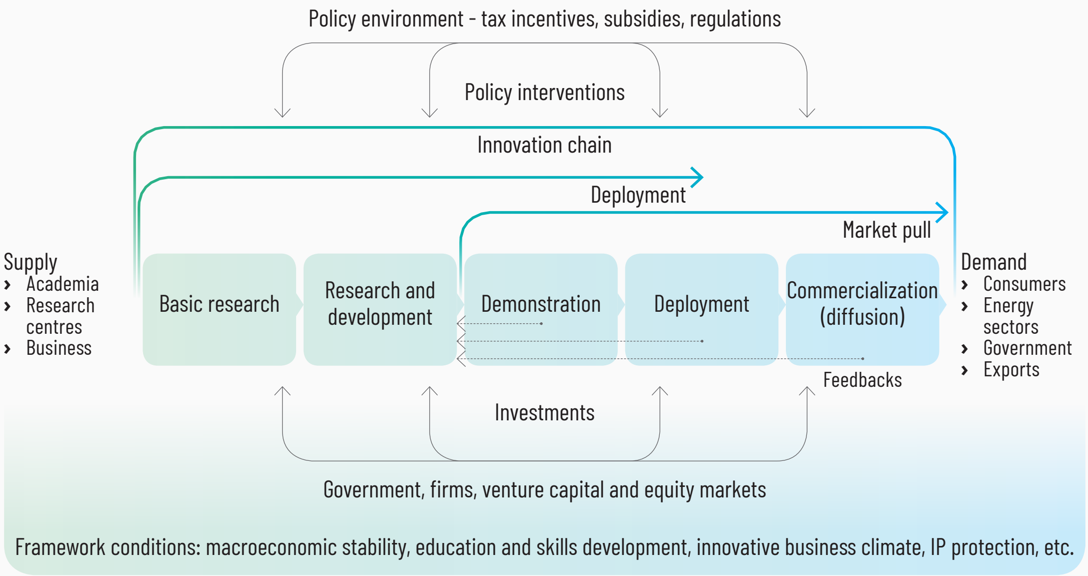
Chemistry research and innovation take place in a broader innovation system. An innovation ecosystem includes diverse actors and complex relationships. It also includes institutions (e.g. research and educational institutions, businesses, investors, centres of excellence, funding agencies and policymakers). This ecosystem requires material resources (e.g. funds, equipment and facilities), as well as human resources including students, faculty, staff, industry researchers and industry representatives (Jackson 2011). Figure 3.1 introduces the elements of the innovation ecosystem.

## The technology innovation chain

The technology innovation process consists of three basic stages: invention, innovation and diffusion (Schumpeter 1954). Invention refers to the development of an idea; innovation is the stage at which an invention is turned into


a new product or process and brought onto the market; and diffusion or dissemination is the stage at which the new product or process obtains a larger market share. Figure 3.2 presents a slightly more detailed representation of the technology innovation process, including five stages: basic research; research and development; demonstration; deployment; and commercialization. This figure also features elements and actors in the broader innovation ecosystem. Within the system there are several underlying forces at play. They include a push force driving innovation through the research sector, and a pull force driving innovation through consumer preferences, market trends and government policies. As the research and innovation process advances towards commercialization, the role of research bodies and public investment decreases while that of the private sector increases.

**Figure 3.2** **Technology innovation chain and key enabling factors (adapted from International Energy Agency 2008, p. 170)**



### Technology readiness measuring systems and the Valley of Death

Throughout the innovation chain, decision moments (or gates) are built in to assess the status of the innovation and determine conditions for next steps. A Technology Readiness Level (TRL) measuring system has been developed to help measure the promise, maturity and usability of a new technology. Created originally by the National Aeronautics and Space Administration (NASA) in the United States (NASA 2012), it consists of nine levels, starting with the idea and basic principles and ending with successful mission and commercial application. To address specific needs, several institutions, venture capitalists and companies have developed complementary systems such as the Manufacturing Readiness Level, the Commercial Readiness Index and the Investment Readiness Level.

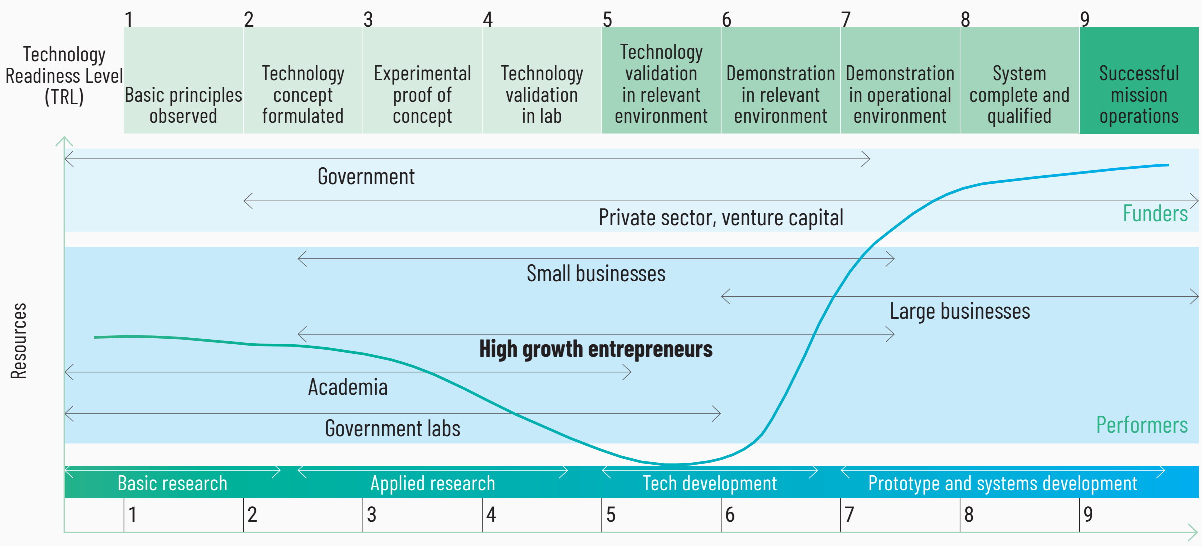
Many technology innovation initiatives are discontinued due to lack of resources, particularly at the stage of technology demonstration and development. The "Valley of Death" is the gap between the "research economy" (a product of academic research and industry-academia cooperation) and the "commercial economy", which transforms the research outcomes into commercially viable products (Figure 3.3) Strategies and approaches to fill the resource gaps between stages 4 (technology validation) and 7 (demonstration in the real world) include: 1) extending the availability of research resources to later stages of development, e.g. by incentivizing academic champions; 2) earlier commercial investment through reducing perceived risks, e.g. by prototyping, or brainstorming dialogues with investors on nascent technologies and potential capabilities; and 3) infrastructure investments designed to benefit the environment as a whole, e.g. through rapid prototyping of infrastructure, lowering start-up entry costs, and increasing successful attempt rates (Jackson 2011).

## 3.2 Key actors in advancing sustainable chemistry innovation

### Universities/research institutions

Universities and other knowledge-generating bodies advance fundamental research on chemistry. Universities mainly carry out chemical science and engineering research from curiosity-driven, problem-based, empirical, theoretical and (nowadays) also computational angles. Sustainability chemistry research links the chemistry and engineering sciences, bridges curiosity-driven understanding and solving of

**Figure 3.3** Stage of technology readiness and the Valley of Death (adapted from EC 2012, p. 18; Coyle 2011, p. 11)



hard problems, and brings in perspectives from other research disciplines such as toxicology, sociology and business (Whitesides 2015).

Universities no longer confine themselves to the traditional roles of teaching and research, but are increasingly engaging in entrepreneurial and business activities. They are expanding their roles by leveraging from fundamental research to entrepreneurial activities as "entrepreneurial universities" (Clark 1998; Etzkowitz 2002; Mirowski and Sent 2007; Etzkowitz *et al.* 2008) or "third generation universities" (Wissema 2009). In this case, universities are understood to be nucleuses for problem-solvers, inventors and entrepreneurs which are not only creating professionals (first generation universities), or professionals and scientists (second generation universities), but professionals, scientists and entrepreneurs (EC and OECD 2012). Examples of activities closely related to entrepreneurship are patenting, licensing and the establishment of start-up support systems, including spin-off venture formation (Klofsten and Jones-Evans 2000). This development is attributed to the pressure exerted on universities to commercialize their research findings in order to generate revenue which will cover some operating costs, including those of research.

### The chemical industry

The chemical industry often carries out capital- and engineering-intensive applied research and development required for the commercialization of products or services (Whitesides 2015). It also fosters innovation contributing to sustainable development across sectors and regions (e.g. in the health and well-being, packaging, energy, mobility and other sectors) (International Council of Chemical Associations [ICCA] 2017; WEF 2018).

University-industry links are contributing significantly to innovation. In the field of chemistry several innovations have been (co-)invented and/or developed, including heterogeneous catalysis, the synthesis of monomers and production of polymers, small-molecule pharmaceutical chemistry, organometallic chemistry, electrochemistry and energy storage, materials science and surface science (Whitesides 2015). Direct private sector support for universities may include, for example, research funding, training partnerships and technical service contracts (Malairaja and Zawdie 2008). Strong industry-university partnerships could generate complementary strategies for technology development and commercialization, thereby reducing the market risk and optimizing

**Box 3.1 Recommended actions for universities in low- and middle-income countries facing the challenge of transforming themselves into third generation universities**

To strengthen universities in low- and middle-income countries in becoming "third generation universities", a number of actions have been identified by the UN Economic Commission for Europe (UNECE) and the UN Economic and Social Commission for Asia and the Pacific (ESCAP) (UNECE 2012). They include: 1) the preparation of plans to increase the contribution to innovation made by top research universities, based on a detailed assessment of existing constraints and possibilities; 2) the possible merging of existing research institutes with universities, as a result of a rating exercise that would take into account potential and existing synergies, complementarities between research programmes, and access to human and material resources; 3) the organization of centres of scientific and educational excellence in leading research universities, which would be appropriately equipped for the creation of high-level technology and encourage the involvement of students, among other actions identified.

resources for the creation of commercially viable product (Edmondson *et al.* 2012).

### The financial services industry

The financial services industry is of importance in shaping investments and innovation. Experience in areas such as climate change has shown that it plays a decisive role in accelerating (or slowing) the transition towards sustainability. Actors in the financing sectors which affect the sustainability of chemistry-related innovation include both public finance entities (e.g. national/regional or multilateral development banks, export credit agencies, government enterprises/utilities) and private finance entities (e.g. pension funds, sovereign funds, mutual funds, insurance companies, hedge funds, banks, company capital expenditure).

The insurance sector, one of the world's largest investors, can endeavour to ensure that its direct investments contribute to sustainable chemistry innovation. In the banking sector lending decisions can direct funding towards sustainable projects and technologies. Similarly, cutting finance for destructive practices and companies can play an important role in steering the chemical industry and its downstream users towards sustainability. Institutional investors can exert influence by redirecting their investments towards more sustainable practices and companies, and using their influence as shareholders to demand that companies act sustainably.

### Governments

Governments play an important enabling role in fostering chemical innovation (UNECE 2012; United Nations Economic Commission for Africa [UNECA] 2016a; UNECA 2016b) and helping correct market failures to produce innovation. Governments may provide financial incentives, finance infrastructure or directly finance innovation projects (Lopes da Silva, Baptista Narcizo and Cardoso 2012). They may also ensure that innovation barriers are removed by stimulating the demand side (UNIDO 2017). Government can play a particular a role in fostering sustainable chemistry innovation through national industrial policies or national programmes. These functions are in line with the perceived role of government as a facilitator providing enabling instruments and favourable conditions, rather than making specific choices and declarations (UNECE 2012; UNECA 2016a; UNECA 2016b).

### Other actors

NGOs and the general public have traditionally not been engaged in research or been recognized as stakeholders in the innovation process. However, it is now recognized that these groups can make a significant contribution. For example, innovation-focused dialogue among stakeholders may be undertaken in developing new regulatory frameworks or as a response to awareness-raising of NGOs. This approach requires new interaction channels, but may bring in new sustainable chemistry considerations to implement the SDGs (WEF 2018).

## 3.3 Profiting from the potential of sustainable chemistry start-up companies

### The importance of chemistry start-ups for sustainable development

Start-up companies, including those focusing on sustainable chemistry, play an important role in contributing to sustainable economic development (US GAO 2018; WEF 2018). Where they attain their growth ambitions, they contribute significantly to innovation and the creation of jobs and wealth in the larger economy. Start-ups invest heavily in R&D and are more likely to export their goods and services (Storey 1994; Baldwin *et al.* 1995; Kirchhoff *et al.* 2007; Wu and Atkinson 2017). If they are created as international new ventures, they can also act as catalysts for technology transfer across regions and value chains (Oviatt and McDougall 2005). Similarly, they have the potential to apply specific local knowledge that is relevant in less developed parts of the world.

Sustainable chemistry start-ups play an important role in scaling up chemistry innovation.

They develop new, potentially disruptive ideas and attempt to put innovative products on the market. Breakthrough technologies in sustainable chemistry have significant market potential and could transform how the industry perceives performance, function and synthesis (ASBC and GC3 2015).

Sustainable chemistry start-ups are based in many countries. An example of a collaborative start-up network is the GC3 Start-up Network in North America (GC3 n.d.a). The winners of the 2018 Elsevier Foundation Green and Sustainable Chemistry Challenge, for example, from Nepal and Italy, developed novel approaches to sourcing guava leaves and fish bones in order to create new preservatives and fertilizers (Elschami and Kümmerer 2018). Other examples of sustainable chemistry start-ups recognized internationally include:

- an Indonesian start-up that uses seaweed in the production of plastic-free packaging (Langenheim 2018);
- starts-ups from Peru and Singapore that use nanotechnology-empowered water purification filters (OECD 2016); and
- a Kenyan start-up that is providing alternative building materials and products made from recycled plastics (Mbaka 2018).

## Challenges of chemistry start-ups

Start-ups active in the area of chemistry, including those working on sustainable chemistry, face challenges. Difficulties may occur in regard to securing access to finance, marketing, partnerships, commercialization, and access to research infrastructure. Other difficulties include high costs and logistical challenges in feedstock supply, capital requirements to build a commercial scale plant, and technical challenges in making cost-competitive products (Sworder, Zhang and Matheson 2018). Access to finance is challenging, as start-up firms are often built on intangible rather than tangible assets and face a high risk of failure (Söderblom and Samuelsson 2014). Start-ups in developing and emerging economies face particular challenges (Sworder, Salge and van Soest 2017), including lack of basic laboratory infrastructure and of access to capital. However, developing countries may also offer opportunities, for example owing to their lower market density and the opportunity to leapfrog to advanced technologies. Box 3.2 describes start-up challenges identified by sustainable chemistry entrepreneurs (UNEP 2017).

A range of stakeholders and organizations engage in supporting sustainable chemistry start-ups through various stages of the innovation chain, with complementary roles based on their motives for collaboration (Wilson 2015). These stakeholders include universities, research

© The Elsevier Foundation, First and second prize winners of the 2018 Elsevier Foundation Green and Sustainable Chemistry Challenge, Prajwal Rabhindari and Dr. Alessio Adamiano

© UNEP, Carlos Ocampo Lopez presenting on biological alternatives to mercury in artisanal and small-scale gold mining at a workshop on advancing entrepreneurship and start-up initiatives for sustainable chemistry held in 2017

**Box 3.2 Insights from entrepreneurs on challenges for sustainable chemistry start-ups (UNEP 2017)**

Representatives of some 15 sustainable chemistry start-ups from around the world met in Berlin, Germany, in 2017 to identify opportunities and challenges. They discussed, among others, the following:

- *Innovation culture in universities:* Few universities provide chemistry students with training in business, marketing, and other relevant subjects; universities seldom encourage students to create start-ups; co-operation across faculties can support interdisciplinary thinking; there is a need for curriculum reform, as sustainability considerations are still not integrated in standard chemistry courses.
- *Research infrastructure:* More incubators are needed to facilitate sustainable chemistry start-ups; barriers for spin-offs from universities are too high; there is a need to strengthen partnerships between academia and industry/the private sector.
- *Intellectual property, patents and licensing:* Patenting and licensing processes are often lengthy, costly and complicated; where patents are in place, they are often not turned into a product or service; licensing agreements with universities may sometimes hinder entrepreneurship.
- *Business planning and access to finance:* Sustainable chemistry entrepreneurs often lack business expertise (e.g. in developing a business plan); networks and partnerships are crucial to establish a multi-disciplinary team and gain access to capital.
- *Upscaling, marketing, commercialization:* The time it takes for a product/service to become profitable is often lengthy; a thorough analysis of the market is a prerequisite for success (e.g. innovation should be based on market demand); start-ups need realistic milestones and targets.
- *Enabling environment/effective regulation:* Regulations may sometimes create unnecessary burdens for entrepreneurs; registration processes may be too costly and lengthy for start-ups with little capital; an incentive system could help (e.g. tax reductions).

institutions, corporations, business associations, NGOs, funding organizations and governmental institutions.

### Initial coaching and technical support services

In the early development stages, start-ups need to have the right entrepreneurial skill sets. These include: 1) technical skills (necessary to produce the business's product or service); 2) managerial skills (essential for the day-to-day management and administration of a company); 3) entrepreneurial skills (skills for recognizing economic opportunities and acting effectively on them); and 4) personal maturity skills (e.g. self-awareness, accountability, emotional and creative skills) (Kutzhanova, Lyons and Lichtenstein 2009). A basic knowledge and skill set may include learning on topics such as entrepreneurship, scholarship, business modelling and business planning. There is an emerging market for online education platforms that provide full courses and certified modules of university lectures to support start-ups (Yuan and Powell 2013).

The United States Department of State's Global Innovation through Science and Technology (GIST) has supported the development of start-ups, including many initiatives in green chemistry (GIST 2018). This initiative seeks to "empower young innovators through networking, skills building, mentoring, and access to financing to develop start-up solutions that address economic and development challenges". Through training, competitions, resources and interactive online programmes, the initiative supports innovators and entrepreneurs from more than a hundred emerging economies in establishing successful start-ups. This is done through competitions, start-up trainings, and interactive online programmes. The first programme developed by GIST in Latin America was in Medellín, Colombia in 2015. It provided training, an innovation competition, and access to finance in the United States.

Some entrepreneurially oriented universities have set up infrastructure to attract investment for the development of promising high-tech projects (Lockett, Jack and Larty 2012). Dedicated staff provide coaching and technical assistance through technology transfer centres or innovation and commercialization offices (Sergey, Alexandr and Sergey 2015). For example, the Center for Sustainability at Aquinas College in the State Michigan in the United States operates a "*Proof of Concept Center*" providing assistance to green chemistry start-ups (e.g. in licensing and patenting processes).

Obtaining recognition is important for start-ups early on in the process, in order to achieve market visibility and gain a reputation. Start-ups may benefit from participating in award schemes and thematic challenges, early-stage start-up

**Box 3.3** Selected sustainable chemistry awards and pitching events targeting start-up

**Thematic challenges and awards**

- The Elsevier Foundation Green and Sustainable Chemistry Challenge, launched in 2015, is a thematic challenge. Chemistry-related ideas with an impact on sustainable development can be submitted.
- The ISC3 Innovation Challenge, launched in 2018, calls for applications by start-ups pioneering in thematic sustainable chemistry topics that change annually, such as sustainable buildings and living. Its best practices awards are lighthouse examples of sustainable chemistry innovation.

**Start-up pitches and investor forums**

- The GC3 is a multi-stakeholder collaborative based in the United States which promotes sustainable chemistry innovation. It selects start-ups every year to present their sustainable chemicals, materials, products and manufacturing technologies to large companies at its Annual Green & Bio-Based Chemistry Technology Showcase & Networking Event.
- NIW Startups is part of the annual Nairobi Innovation Week in Kenya, where early-stage start-ups (classified into categories such as clean tech, agriculture and food security) present their ideas to an international jury.

pitches and investor forums, and by seeking media coverage as described in Box 3.3.

## Institutional support mechanism/venturing tools

When start-ups advance along the technology innovation chain, more institutional support mechanisms and venturing tools become available. Table 3.1 provides a broad overview.

Both incubator and accelerator type organizations provide nascent firms with advice, business services, networking facilitation and, occasionally, financial support to help them develop and launch their companies (Bøllingtoft and Ulhøi 2005; Hoffman and Radojevich-Kelley 2012; Dempwolf, Auer and D'Ippolito 2014). While incubators "incubate" ideas and set up a business model and company, accelerators "accelerate" the growth of an existing company (Forrest 2018). Figure 3.4 shows key characteristics of these two concepts and how they overlap.

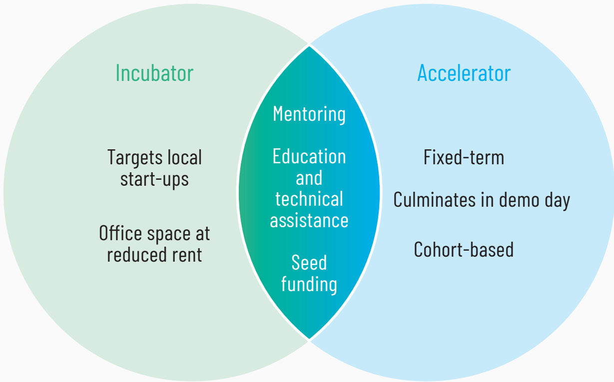
Organizations develop institutional support mechanisms with various subsets of services based on different venturing tools, all with distinct or similar observable characteristics (Dempwolf, Auer and D'Ippolito 2014). Examples include:

- the Center of Studies and Research in Biotechnology (CIBIOT) at Universidad Pontificia Bolivariana, Medellín, Colombia, an initiative that contributes to sustainable chemistry by building capacities in technology transfer projects with technical novelty, market-oriented, scalable and social innovation characteristics;
- the John Warner Chemical Invention Factory of the Technical University of Berlin (Germany), an incubator-like start-up development centre opened in 2018, which provides state-of-the-art laboratories, research infrastructure, scientific mentors and networking opportunities;
- the Think Beyond PlasticTM early-stage innovation accelerator, an accelerator which

**Table 3.1 Institutional venturing tools (adapted from OECD 2012; Dempwolf, Auer and D'Ippolito 2014; Root 2017)**

| Venturing tool | Description |
|---|---|
| University technology innovation offices | Universities help start-up projects turn first ideas into inventions and innovations, e.g. by providing access to research infrastructure, technical equipment and support in patenting. |
| Incubators | Incubators take in young start-up companies and provide them with affordable space, shared offices and other services. This helps narrow down the business idea and connect to funders. |
| Accelerators | Accelerators give developing companies access to mentorship, investors and other support that help them become stable, self-sufficient businesses. This is usually cohort-based and |
| fixed-term. | Large enterprises organize start-up support, with a view to improving corporate competitiveness following their own strategic or financial objectives. This can include business incubation or acceleration. It usually addresses more mature start-ups at later stages of development. |
| Corporate ventures | Large enterprises organize start-up support, with a view to improving corporate competitiveness following their own strategic or financial objectives. This can include business incubation or acceleration. It usually addresses more mature start-ups at later stages of development. |
| Governmental/NGO support | Public or non-profit venture development organizations provide a portfolio of services to start-ups, with the intention of creating positive economic, social or environmental impacts. |

**Figure 3.4** **Venn diagram of incubator and accelerator characteristics (adapted from Dempwolf, Auer and D'Ippolito 2014, p. 14)**




supports sustainable chemistry start-ups from different world regions; and

- Accelerace (Denmark), a late-stage innovation accelerator that is part of the Danish national Scale-up Denmark initiative, which is scaling up start-ups within tech, food tech, clean tech, life sciences and welfare technologies.

A wider range of venturing tools are shown in Figure 3.5. This figure highlights the relevance of venturing undertaken at various stages of the innovation chain. Some tools are more relevant for start-up support early on, while others (e.g. corporate venture capital, strategic partnerships and acquisitions) are more relevant at later stages.

## Financing instruments and mechanisms

In most cases, start-ups require funding from investors because their own financial resources are not sufficient to cover various costs at the different development stages. For example, large amounts of capital are often needed for technical equipment, laboratories, access to research infrastructure, patent fees and salaries. One of the most important decisions entrepreneurs

**Figure 3.5** **Venturing tools supporting start-ups at different innovation phases (adapted from IESE Business School 2017, p 21)**

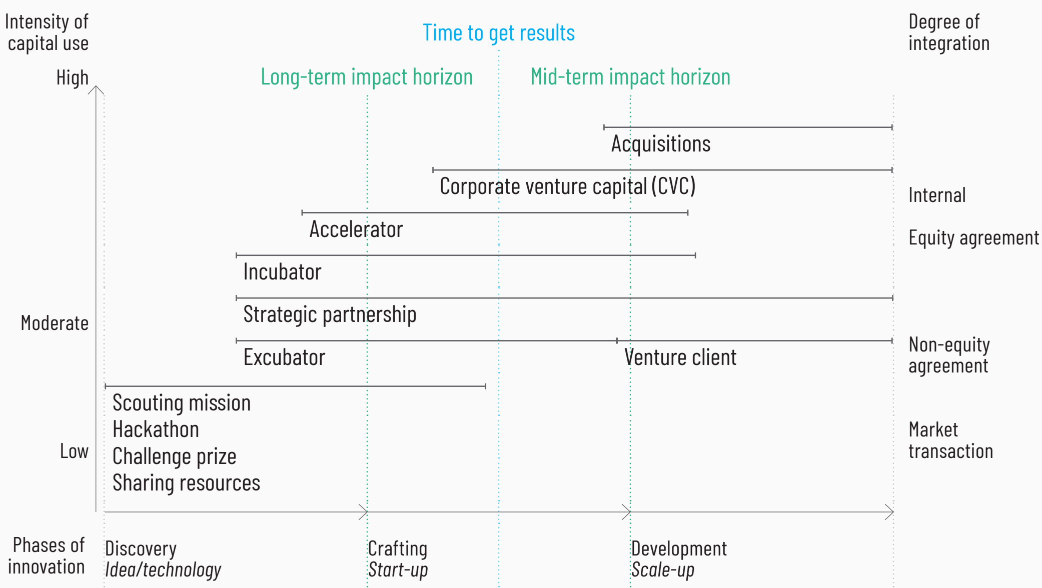


**Table 3.2** **Potential private investors for sustainable chemistry start-ups (adapted from OECD 2012 and Root 2017)**

| Investor | Description | Typical funding instrument |
|---|---|---|
| Business angels/angel investor networks | Individuals or networks with disposable income invest in start-ups. Usually they invest cash, provide time for coaching/mentoring, and make business introductions. | Equity and mezzanine |
| Banks | Bank loans are one of the most common tools for accessing finance. Banks request collateral or guarantees in exchange for loans. | Debt |
| Private equity (PE) firms | Private equity firms invest directly in private companies. They tend to focus on more mature start-ups and to invest much larger amounts than do venture capital firms. | Equity |
| Venture capital (VC) firms | Venture capital refers to investments made in exchange for equity. VC focuses on funding, developing and expanding start-ups which earn the investors return on their capital in a fairly short time. | Equity and mezzanine |
| Corporate ventures | Corporate ventures are used by large firms to invest in innovative start-ups in order to improve corporate competitiveness with either strategic or financial objectives. | Equity and mezzanine |
| Impact investors (e.g. foundations or public/semi-public funders such as development finance institutions) | Impact or social investors refers to funds that invest with the intention of creating a positive social or environmental impact. As an eclectic group, they include high net worth individuals (HNWIs), family offices, foundations, banks, pension funds, impact-focused VCs and angels, and development finance institutions (DFIs). | Grant, debt and equity |
| Crowd funding platforms | Crowd funding is the practice of raising money from a large group of individuals, typically through an online portal. | Grant, debt and equity |

**Table 3.3** **Examples of investments in sustainable chemistry start-ups by different investors**

| | |
|---|---|
| Public grants | Individuals or networks with disposable income invest in start-ups. Usually they invest cash, provide time for coaching/mentoring, and make business introductions. |
| | Enerkem and the City of Edmonton (Canada): Enerkem formed a partnership with the City of Edmonton for the construction of a facility that converts non-recyclable, non-compostable municipal solid waste into liquid biofuels and chemicals. It has since secured several strategic partnerships to co-develop additional plants. Enerkem Alberta Biofuels, a subsidiary of Enerkem Inc., has received a Canadian dollars 3.5 million grant from the Government of Canada through the Western Innovation (WINN) Initiative. |
| Public investors | The Brabant Development Agency Capital (BOM Venture Capital) Fund (Netherlands), created by the Dutch Government and the Province of Brabant, finances companies and start-ups by providing equity capital and subordinated loans of up to euros 2.5 million. Another example is Innofund (China), an equity fund developed by the Chinese government for which sustainable chemistry start-ups are eligible. The European Investment Bank supports start-ups, including those active in sustainable chemistry, through the European Investment Fund (EFSI), e.g. under the Early Stage Window of EFSI Equity (InnovFin Equity). |
| Private equity | Capricorn (Belgium), a private venture capital firm with its own sustainable chemistry fund (CSCF), achieved its first milestone capital, closing at euros 50 million in December 2016. The portfolio included three start-ups from Belgium, Germany and the United States. |
| Mezzanine funding | The Green Centre (Canada) helps commercialize academic and entrepreneurial discoveries. Formed in 2009, it was funded by the Government of Ontario, the Government of Canada and various industry partners, among other technical support. It provides 8,500 square feet of state-of-the-art laboratory facilities for innovation and the advancement of chemistry technologies. |
| Impact investors (e.g. foundations or public/semi-public funders such as development finance institutions) | Impact or social investors refers to funds that invest with the intention of creating a positive social or environmental impact. As an eclectic group, they include high net worth individuals (HNWIs), family offices, foundations, banks, pension funds, impact-focused VCs and angels, and development finance institutions (DFIs). |
| Crowd funding platforms | Crowd funding is the practice of raising money from a large group of individuals, typically through an online portal. |

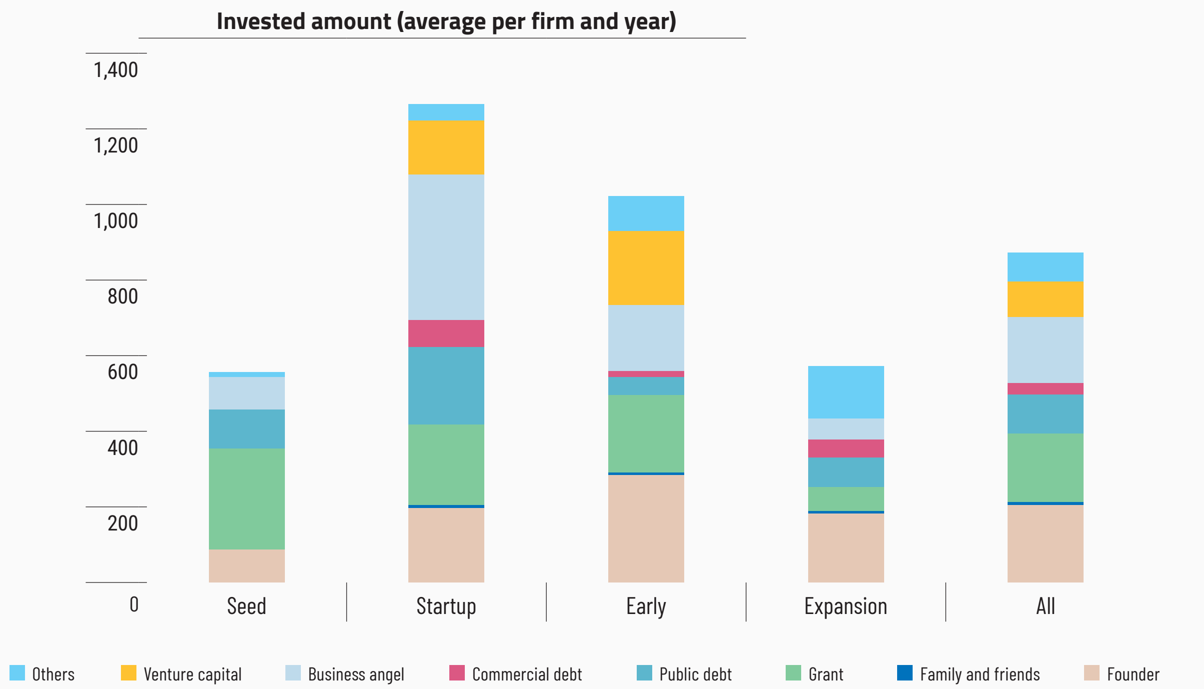
need to make at some point is how to raise money (and whom to ask for it) (Root 2017).

Four main types of funding instruments are available for start-ups: grants, debt financing (loans), equity financing, and mezzanine. A grant typically does not obligate the recipient to repay the funds. Debt financing means accepting capital with the promise of repaying the principal with interest. Equity financing means an investor puts money into a start-up in exchange for a percentage of the company's shares. Mezzanine is a mix of debt and equity financing features (Wilson 2015; Root 2017). Potential private investors in sustainable chemistry start-ups are shown in Table 3.2, which emphasizes that investors use different funding instruments.

Research indicates that some investors may be more appropriate partners for start-ups in earlier development stages, and others in later stages of a firm's development (Söderblom and Samuelsson 2014; Wilson 2015). One of the main reasons for this is that investors have different strategic motives for providing seed money (Root 2017). For example, a publicly funded development finance institution usually invests with the intention of creating a positive social or environmental impact while a corporate venture invests with a view to gaining competitive advantage over other market players. The phenomenon of different investors investing at different development stages is illustrated in Figure 3.6.

Real-world examples of investments in sustainable chemistry start-ups demonstrate that different funding instruments are used by start-ups, and that start-ups have taken different decisions on whom to partner with in order to access finance (Table 3.3). Several public and private stakeholders have established different types of funding opportunities for sustainable chemistry start-ups, including national grants, public investment agencies and equity-based Sustainable Chemistry Funds, as well as cooperative approaches involving public and private partners.

**Figure 3.6** **Start-up development stages and typical investors along the innovation chain (Swedish krona thousand) (adapted from Söderblom and Samuelsson 2014, p. 10)**



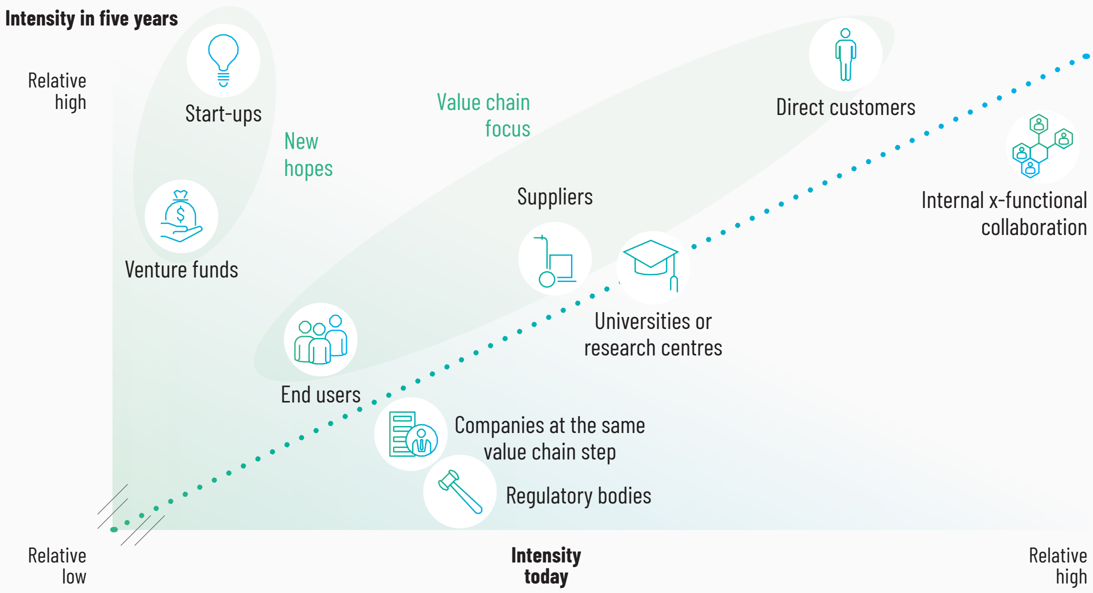

Average invested amount in each phase. The mean in thousand Swedish krona for the respective sources for all firms in the particular phase is reported.


© Enerkem, manufacturing of biofuels and renewable chemical products from non-recyclable waste

## Chemical companies' engagement in start-ups

While many large chemical companies have research departments, industry leaders increasingly recognize the potential of start-ups. In a recent survey, representatives of large companies responded that in the future they expect "a much higher intensity of collaboration with start-ups than today"; by 2022 they foresee collaboration with start-ups and venture funds surpassing in intensity collaborative approaches with suppliers, universities or end users (WEF 2018).

**Figure 3.7** Chemical industry leaders´ view of the evolution of the intensity of collaboration with other stakeholders (adapted from WEF 2018)



In taking a strategic approach to identifying and/or supporting start-ups, and to obtaining a growing portfolio of associated start-ups, a number of large corporations have special programmes and instruments dedicated to different sub-goals associated with ultimately gaining competitive advantage (Table 3.4). These can be distinguished as corporate incubator, corporate accelerator, corporate venture capital and corporate strategic partnerships. A Boston Consulting Group (BCG) research study (Brigl *et al.* 2016) found, however, that the chemical industry mainly used corporate venture capital to support start-ups although there are more recent examples of accelerators and incubators. Examples of such ventures led by the chemical industry include BASF Venture Capital, Dow Venture Capital, DuPont Ventures, Solvay Ventures (and Aster Capital along with Alstom and Schneider Electric) and Evonik Venture Capital (Faulkner and Berenshteyn 2013).

## 3.4 Creating an enabling framework to support sustainable chemistry innovation

### Promoting open and collaborative innovation

The open innovation paradigm envisages that companies can no longer afford to innovate by carrying out R&D activities single-handedly (Şimşek and Yildirim 2016). Instead, they are engaging research and knowledge institutions,

**Table 3.4 The corporate approach to start-up development (Brigl *et al.* 2014, p. 6)**

| | Business incubation | | | |
|---|---|---|---|---|
| | Corporate incubator | Corporate accelerator | Corporate venture capital | Corporate strategic partnerships |
| **Objective** | › Support start-ups with an array of business support resources and services, orchestrated by incubator | › Support start-ups with a structured programme using fixed curricula | › Support existing companies with capital in exchange for equity shares | › Partner with existing companies to drive joint value creation |
| **Benefits to start-up partner** | › Office space, hardware | › Office space, hardware<br>› Skilled mentorship and coaching<br>› Start-up network<br>› Technical support<br>› Potential funding support | › Financial support<br>› In many cases, close cooperation with corporate unit as equal partner<br>› Mentorship (in some cases) | › Extend market potential<br>› Close missing IP gap<br>› Limit investments in non-core corporate capabilities<br>› Create competitive advantage |
| **Benefits to company** | › Outsourced R&D function | › Wider search field for corporate development and growth options<br>› "First pick" potential in case of promising start- up business | › Equity share in company with strong growth and profit potential<br>› Portfolio extension, especially in advanced technologies and products | › Extend market potential<br>› Close missing IP gap<br>› Save investments in non-core corporate capabilities<br>› Create competitive advantage |
| **Investment** | › Up to 25 per cent of equity | › Partly without equity; in some cases up to 5 per cent | › 20 per cent or less | › Possible equity exchange, depending on partnership format |
| **Start-up stage** | › Early stage, without existing business | › Start-ups technically ready to "spread wings" | › Small existing companies with high growth potential | › Innovative companies, but not necessarily new players |
| **Time frame** | › 12-36 months | › Typically 3 months | › 5-7 years | › Depends on product cycle |

**Box 3.4** **Open collaborations in sustainable chemistry innovation**

The Eco-Efficient Products and Process Laboratory (E2P2L) is a unique international research entity dedicated to renewable and sustainable chemistry. Based in Shanghai, China, its purpose is to develop innovative eco-efficient products and environmentally benign processes capable of reducing dependence on oil and other fossil resources. E2P2L was set up in November 2011 by the French National Scientific Centre (CNRS), the Belgian chemical company Solvay, the Ecole Normale Supérieure de Lyon in France, and the East China Normal University. In 2013 the Lille University of Science and Technology in France and the University of Fudan in Shanghai joined the consortium. Another example is the GC3, a multi-stakeholder collaborative that drives the commercial adoption of green chemistry by catalysing and guiding action across all industries, sectors and supply chains (GC3 n.d.b).

as well as chemical suppliers and users, financial institutions, engineering companies and digital solution providers, in research and innovation (Huizingh 2011). These efforts can also include collaboration with competitors in seeking lower operational costs and lower risks (Şimşek and Yildirim 2016). Finally, sustainable innovations need scaling up and sharing across sectors if they are to have the potential to shift the sector as a whole.

As shown in Figure 3.8, novel forms of collaboration are being created between different internal entities of chemical companies, as well as with external partners, customers and consumers, regulators and other civil sector communities. Partnerships are often driven not only by science and technology, but also by SDG-related issues, and are implemented with cross-sectoral, global and diverse markets in mind (WEF 2018).

To manifest greater collaboration and partnership among actors, a number of specific concepts and models may be introduced. For example, science and technology parks present opportunities to innovate in open systems where technology developers and diffusers work at one location to translate innovations from universities and research institutes into markets (Şimşek and Yildirim 2016). Newly established research centres, technology promotion offices and

**Figure 3.8** **New collaboration approaches in the chemical industry (adapted from WEF 2018)**

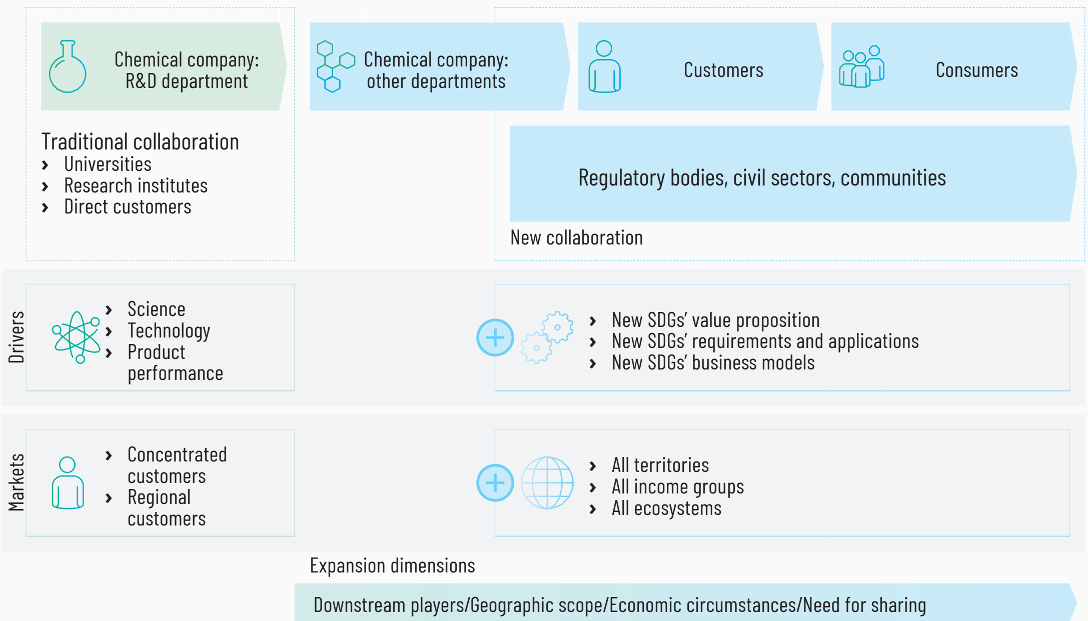
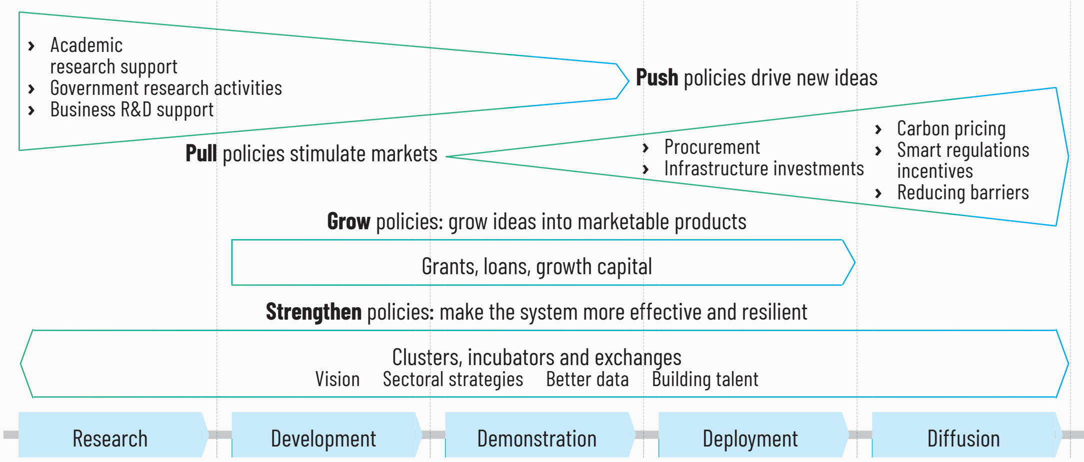


**Figure 3.9** Policy interventions that foster technology innovation (adapted from Elgie and Brownlee 2017, p. 15)




joint institutes use a similar approach of co-creating value through increased collaboration between stakeholders (Wissema 2009). Industry is opening up to more collaborative innovation compared with some five years ago, although a large majority of industry stakeholders still face internal collaboration challenges (WEF 2018). Intermediaries play an important role in facilitating such collaboration innovation (WEF 2018).

## Enabling policies to promote sustainable chemistry innovation

The national innovation systems approach (OECD 1997) stresses that flows of technology and information among people, enterprises and institutions are key to the innovation process. For stakeholders and policymakers interested in advancing sustainable chemistry innovation, an understanding of the national innovation system can help identify leverage points to identify policy interventions.

Enabling policies and financing by governments are an important dimension of the innovation system. They are factors that can be used to correct inefficiency and distortions in innovations. Elgie and Brownlee (2017) divide potential policy approaches or interventions related to innovation into four categories: 1) push policies driving new ideas; 2) pull policies helping to stimulate market demand; 3) grow policies helping to grow ideas into marketable products; and 4) strengthen policies that cut across the clean innovation system, making it more effective and resilient.

**Table 3.5** Examples of push and pull policies to advance sustainable chemistry innovation

| Type of policy/intervention | Example |
|---|---|
| Push policies (driving new ideas and innovation) | › Tax incentives for start-up initiatives<br>› Co-financing or subsidization of science and technology parks (STPs) which include sustainable chemistry components<br>› Sllocating a specified percentage of gross domestic product to R&D and venture funds for start-ups<br>› Increasing the quality of physical infrastructure (academic and research institutions, innovation and technology hubs, makerspaces and internet infrastructure)<br>› Sdopting open and inclusive principles for innovation, with institutions mandated to stimulate open, inclusive, social and collaborative innovation |
| Pull policies (creating market demand for innovation) | › consumer education and awareness-raising<br>› financial incentives to consumers (e.g. subsidies for sustainable chemistry products)<br>› government procurement to purchase eco-labelled products |

While these are general categorizations, this framing illustrates how public interventions may be structured to shape different elements of the innovation system in a direction which supports sustainable chemistry innovation. From the point of view of effectiveness, in certain cases market-based policy instruments (e.g. taxes and tradable permits) tend to induce more innovation than direct regulation. Other characteristics of policy instruments that play a role include stringency, predictability, flexibility, depth and incidence (OECD 2011).

### Exploring opportunities for green bonds

Financial instruments and tools can play a role in driving the transition towards sustainable chemistry innovation. Green bonds are an example. These bonds can be defined as "a debt security that is issued to raise capital specifically to support climate related or environmental projects" (International Bank for Reconstruction and Development and World Bank 2017). An important dimension of setting up a green bond is defining criteria, which include green or sustainable chemistry considerations (Ernst & Young [EY] 2016). Green bonds designed to encourage sustainability come with tax incentives such as tax exemption and tax credits. This makes them a more attractive investment than a comparable taxable bond. While green bonds are currently focused on climate change, their potential to advance sustainable chemistry investment and innovation could be explored.

## 3.5 Measures to strengthen sustainable chemistry technology innovation and financing

Accelerating research and innovation through collaborative and enabling action, including through start-up companies, is key to reaping the promise of green and sustainable chemistry to make a contribution to the 2030 Sustainable Development Agenda. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to strengthen sustainable chemistry technology innovation and financing.

- Use green and sustainable chemistry criteria to assess whether innovations in chemistry are compatible with the 2030 Sustainable Development Agenda.
- Strengthen open and collaborative innovation mechanisms involving research organizations, the private sector, governments and civil society.
- Strengthen support mechanisms for sustainable chemistry start-ups in universities, research institutes, the private sector and all levels of government.
- Strengthen financial instruments for investment in sustainable chemistry innovation, for example through green bonds and venture capital or other multi-stakeholder funding mechanisms.
- Develop guiding policies and criteria for financial resources to support green and sustainable chemistry innovation.
- Review and strengthen innovation policies to ensure that they enable, and do not create, barriers to sustainable chemistry innovation.

# 4/ Evolving and new business models

## Chapter Highlights

New and evolving business models have significant potential to advance sustainability in the chemical industry, if properly applied.

Business models of relevance include service-oriented models (e.g. Chemical Leasing) and coordination benefits models (e.g. chemical parks).

Business models that decentralize production (e.g. 3-D printing) and distribution (e.g. e-commerce) are on the rise, creating opportunities but also raising concerns.

Social entrepreneurship business models are relevant for chemicals and waste, and are emerging around the world.

A business model defines how an organization creates, delivers and captures value in economic, social, cultural or other contexts. Business models are constantly evolving. While they may create opportunities, they can also create potential concerns from a chemicals and waste management perspective. This chapter discusses several evolving and new business models which are considered relevant from a chemical and waste management perspective. They range from service-oriented models, to social enterprises, to models in which production and sales are decentralized.

## 4.1 Business models in a fast-changing world

In a fast-changing world, new business models with direct implications for the chemical industry are evolving rapidly – providing opportunities to advance sustainability by increasing resource efficiency, and by reducing the use of hazardous chemicals and chemical pollution. Business model innovations for sustainability may be defined as creating "significant positive and/or significantly reduced negative impacts for the environment and/or society, through changes in the way the organization and its value-network create, deliver value and capture value or change their value propositions" (Bocken *et al.* 2014). Business models that have a strong focus on sustainability and circularity include green product- and process-based models, waste regeneration systems, efficiency optimization, management services, and industrial symbiosis models (Beltramello, Haie-Fayle and Pilat 2013). Other emerging business models, such as consumer-centric models and social enterprises, are directly driven by sustainability considerations but are equally relevant to the sound management of chemicals and waste.

## 4.2 Service-based systems, including Chemical Leasing

Service-based business models, or "product-service systems" (PSS), are an alternative to the traditional sales concept of industrial production. PSS can be broadly defined as "a combination of products and services in a system that provides functionality for consumers and reduces environmental impact" (Hänsch Beuren, Gomes Ferreira and Cauchick Miguel 2013). This means goods continue to be owned by the provider(s).

What a PSS customer actually purchases is the functionality or performance of the goods in the form of a service. A business that offers a service does not seek to maximize sales of a chemical product, but to provide the service in a cost-effective and sustainable manner. Research suggests that service-based business models incentivize industry to change product design; advance life cycle thinking and stewardship; and reduce environmental footprints throughout a product's life cycle (Agrawal and Bellos 2015).

## Chemical management services: win-win opportunities

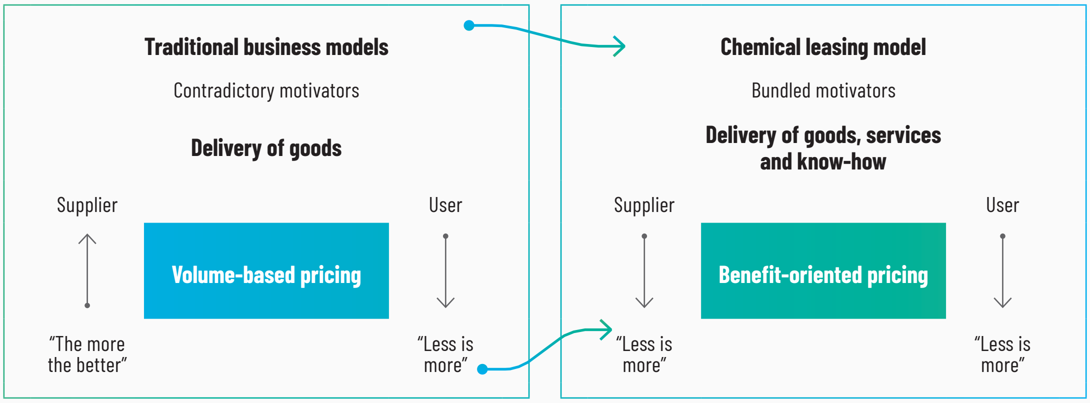
In the chemicals sector PSS are referred to as "chemical management services" (CMS). CMS generally involve a strategic, long-term contract between the service provider and the client. The service provider is compensated based on the quality and quantity of the services provided, rather than on the volume of chemicals sold. Proponents of CMS note that the service provider and customer have the same objective: to reduce the overall life cycle costs of chemicals management (United Kingdom Chemicals Stakeholder Forum 2013). CMS services may encompass (and be provided at) all stages of the chemical life cycle, including production, transport and storage. They can exist in the automotive, air transport, electronics, heavy equipment, food and pharmaceutical, and steel industries, among others. Through technological solutions (e.g. material substitution, pollution prevention, and end-of-life management practices) CMS can help reduce the risks associated with the production and use of chemicals. They can also stimulate sustainable production and a decrease in product consumption levels (Askar 2006).

## The market for chemical management services is growing

The CMS supplier community and market have grown significantly in recent years. Annual growth in revenue for CMS providers exceeded 7.28 per cent per year between 2011 and 2016, from around US dollars 2,192 million to US dollars 3,115 million. Revenue growth in 2016 is estimated to have been at the lower end of the 5-10 per cent range, but is expected to increase to 9-14 per cent in 2017-2022. The profitability outlook for 2017-2022 is projected to improve slightly. Companies using CMS include Haas TCM, PPG Industries, KMG Chemicals, Henkel, ChemicoMays, BP, Quaker Chemical, EWIE Co, Intertek and Chemcept (Technical Progress 2018).

© UNIDO, 2018 Global Chemical Leasing award ceremony, 6 November in Vienna

**Figure 4.1** Traditional business models vs. Chemical Leasing (adapted from Joas, Abraham and Joas 2018, p. 398)






Chemical Leasing refers to a business model whereby suppliers sell services (e.g. the number of cars painted) rather than chemicals, creating incentives to minimize the use of chemicals and maximize resource efficiency.

## Chemical Leasing: a successful application of chemical management services

Chemical Leasing is a type of CMS whereby "the functions performed by the chemical serve as the unit of payment and chemical suppliers and users work together to optimize chemical use in fulfilling the function" (Joas, Abraham and Joas 2018). Responsibility for the application, handling, storage and disposal of chemicals is thus shifted from the user to the chemical supplier. The supplier, in turn, takes over management of the entire life cycle. Figure 4.1 contrasts traditional business models and the Chemical Leasing model.

Chemical Leasing can be used whenever chemicals are needed to provide a particular function or service. Examples include industrial cleaning and degreasing of parts in the metal processing industry; bonding of boxes in the packaging industry; cleaning of bottles, pipes and vessels in the beverage industry; lubrication of conveyor belts in the beverage industry;

**Box 4.1** Chemical Leasing in a middle-income country: wastewater treatment in Colombia

A Chemical Leasing project was implemented in Colombia's petroleum industry through a partnership between Ecopetrol and Nalco, a chemicals provider specializing in water treatment. The aim of this project was to treat wastewater from oil production processes in environmentally sound and cost-effective ways. Following project implementation, there was a 20 per cent reduction in chemicals consumption while water treatment costs were reduced by 80 per cent (US dollars 2.2 million) over 10 months (Moser and Jakl 2014). The unit of payment shifted from dollars per kilogram treatment agent to a unit price (per kilogram barrel of fluid) for the treatment service. This project won the first Global Chemical Leasing Award gold medal in 2010 (Jakl 2011).

© UNIDO, Chemical Leasing Pilot Project in Colombia application of agrochemicals; corrosion and surface protection in the automotive and electric appliances industry; and cleaning in the hospitality sector (Joas, Abraham and Joas 2018).

The Chemical Leasing business model has been successfully implemented for almost two decades in a number of countries (Jakl and Schwager 2008; UNIDO 2016; OECD 2017). At the global level, the UNIDO Global Chemical Leasing Programme has promoted this business model since 2004 (UNIDO 2019). An example of a successful Chemical Leasing approach in a middle-income country is presented in Box 4.1. The 2016 Declaration of Intent on Chemical Leasing has been signed by Austria, El Salvador, Germany, Serbia, Sri Lanka and Switzerland. Additional countries may consider joining (Chemical Leasing 2016).

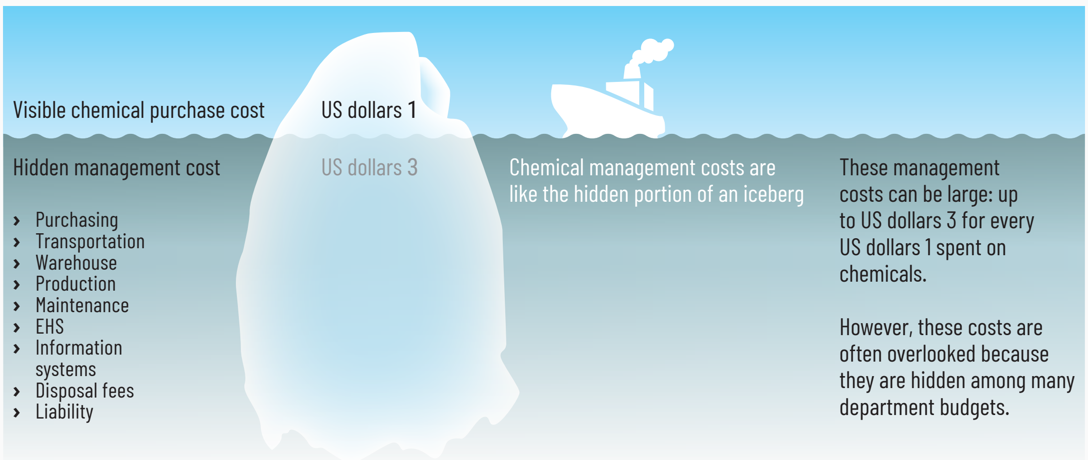
### Economic perspectives on chemicals management services

The economic advantages of Chemical Leasing have been analyzed. A recent study (OECD 2017) reported that the benefits of increasing the user's competitiveness include direct cost savings (reduction of chemical quantities if processes are further optimized); indirect cost savings (through energy and waste management); access to better knowledge, with improvement of processes and reduction of risks; and reliable, long-term business relationships. In addition, the benefits of increasing the supplier's competitiveness include higher profits (monetary reward for supply of expertise and services); reduced raw materials costs; reliable, long-term business relationships; access to knowledge about the application of chemicals; and first-hand experience concerning areas for improvement/innovation of substances.

One economic incentive for customers to switch to CMS can be the reduction of the often hidden costs of the management, use and purchase of chemicals (Figure 4.2). Implementing a CMS programme may result in significant cost savings; further incentives include outsourcing of functions that do not represent a core competency of the company, while manufacturing processes and data management can also be strengthened (Chemical Strategies Partnership n.d.a).

Research shows that Chemical Leasing has improved the economic and environmental performance of companies across the chemicals supply chain and provided access to new markets (Moser and Jakl 2014; Joas, Abraham and Joas 2018). In Austria alone, some 4,000 companies were identified as having the potential to benefit from Chemical Leasing, potentially reducing annual use of chemicals by one-third and costs by 15 per cent (OECD 2013). Nevertheless, the uptake of Chemical Leasing has not been as rapid as it could be. More work is needed to

**Figure 4.2** **Visible and hidden chemicals management costs (based on Bierma and Waterstraat 1997, p. 3; adapted from CSP n.d. b, p. 6)**



understand and overcome the obstacles which hinder the uptake of this approach.

## 4.3 Coordination benefit models: eco-industrial parks and chemical parks

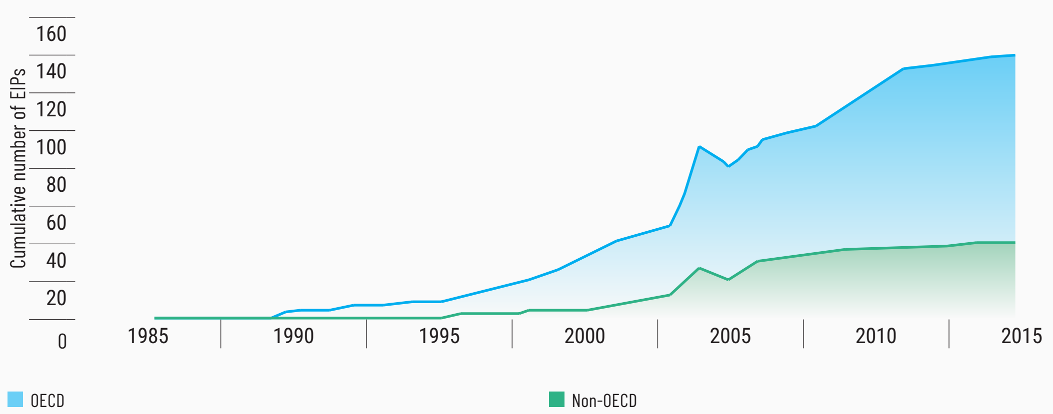
Coordination benefit models are business models based on the coordination of nearby agents, where better economic and environmental benefits can be obtained than if there were no coordination. In the context of coordination between companies located near one another, a coordination benefit model can be referred to as "industrial symbiosis" (Bilsen *et al.* 2013). From a chemicals management perspective, both eco-industrial and chemical parks are of interest. While eco-industrial parks may host a wide range of companies, including chemical companies, chemical parks specifically host chemical companies.

### Eco-industrial parks

Chemical companies may be part of eco-industrial parks (EIPs) in which businesses cooperate with each other and with the local community to reduce waste and pollution and efficiently share resources (e.g. information, materials, water, energy, infrastructure and natural resources). They may be planned from scratch or evolved over time. The well-researched Kalundborg Eco-Industrial Park in Denmark is an example of the latter. Companies in the region collaborate in using each other's by-products and otherwise share resources (Chertow and Park 2016). The number of EIPs is increasing (UNIDO, World Bank Group and German Corporation for International Cooperation [GIZ] 2017). Around 250 existed globally in 2018, compared with only 50 in 2000 (World Bank 2018). While the EIP concept mainly originated in Northern Europe, an increasing focus by international development organizations has led to the scaling up of these parks in developing countries (Kechichian and Jeong 2016).

Evidence of the economic benefits of eco-industrial parks is well-documented. Firms in Ulsan Mipo and Onsan, part of the Republic of Korea's Eco-Industrial Park Initiative, have invested US dollars 520 million in energy efficiency, industrial symbiosis, waste management and other environmentally friendly improvements. That investment has yielded US dollars 554 million in savings, while the firms have generated US dollars 91.5 billion in revenues (UNIDO, World Bank Group and GIZ 2017; World Bank 2018). The initiative is part of the country's Eco-Industrial Park Program, led by the Korea Industrial Complex Corporation (KICOX), which has resulted in 56 new patents, savings of 6.48 million tonnes of $CO_2$ equivalent, and collective financial benefits of

**Figure 4.3** Global growth of eco-industrial parks (EIPs) (adapted from Kechichian and Jeong 2016, p. 15)



US dollars 1,680 million (World Business Council for Sustainable Development [WBCSD] 2018).

### Ownership and funding of eco-industrial parks

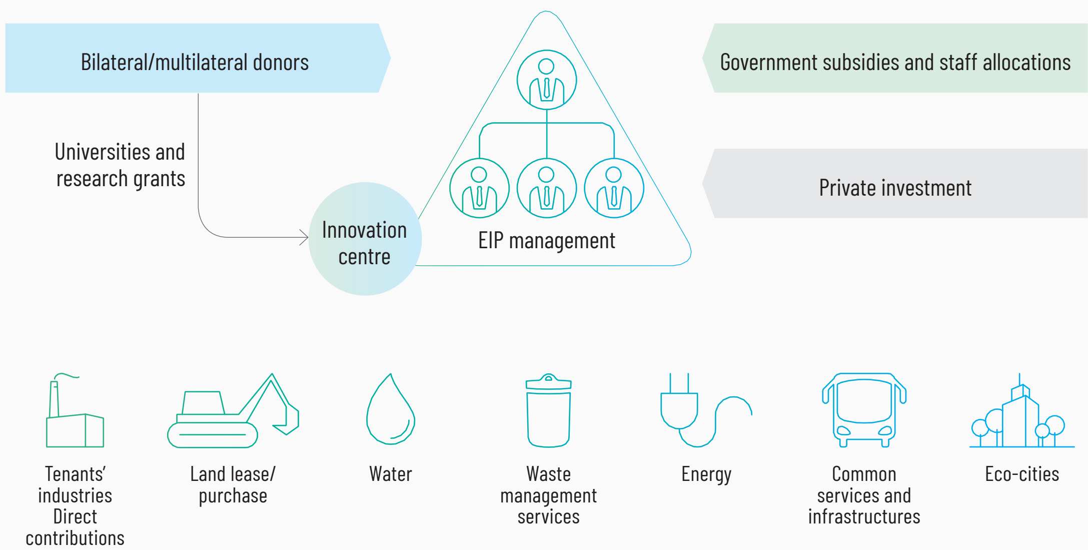
In many cases the land where eco-industrial parks are located is owned by the government, although it may be privately owned. At the development stage the most common financing options are public investment or a public-private partnership. Some parks may also attract foreign investment (Erkman and Van Hezik 2016). A park can request external funding when it is created and during the first years of operation, but it should be economically sustainable in the long run. Private investment, government subsidies and multi/bilateral donor support are among the main external funding sources. Companies are likely to become interested in becoming tenants if they perceive the added value of a park's services (UNIDO 2017). Figure 4.4 shows sources of revenue for eco-industrial parks.

### What are chemical parks and what are their benefits?

A chemical park is a business model that brings together raw material suppliers, chemical manufacturers, producers of specialty chemicals, service providers and other companies at one site (American Institute of Chemical Engineers 2011). It can be defined as a "chemical manufacturing complex which possesses controlled entrance and exit points and accommodates several separately owned chemical manufacturing companies" (Dambmann and Allford 2003). These sites, managed professionally, provide a range of services, allowing investors and businesses to concentrate on their core fields. The concept, which originated in the 1990s in Germany, has expanded to other regions and countries, particularly China. The main drivers of chemical parks in China are restructuring and improvement of technological standards in the country's chemical industry, and the promotion of regional economic development through making investment more attractive to foreign and domestic investors. Chemical parks in China are managed at both provincial and national levels (Hauthal and Salonen n.d.).

Chemical parks can have numerous benefits for tenants from both economic and environmental perspectives. A study carried out at the Rizhao Economic and Technology Development Area in China found that economic benefits resulting from sound environmental standards, tax preferences, material substitution and financial subsidies were critical drivers for stakeholder participation in industrial symbiosis (Yu, Han and Cui 2015). Kalundborg Park in Denmark, a pioneering site for chemical an industrial park,

**Figure 4.4** Eco-industrial parks' sources of revenue (adapted from UNIDO 2017, p. 49)



**Box 4.2 The Shanghai Chemical Industry Park (Zeng and Bathelt 2011)**

The Shanghai Chemical Industry Park, in operation since 2004, is the site of chemical production by the petroleum industry. It is about 29.4 $km^2$ in size and has direct access to the Pacific Ocean. The park is a fully developed industrial area, equipped with infrastructure including streets, internal pipelines, public utilities and environmental protection facilities. All of these have been provided by the Shanghai Chemical Industry Park Development Corporation, which operates and manages the park. In 2006 the park hosted 14 chemical firms with a labour force of 3,250 and total sales of 29.0 billion Yuan (around US dollars 3.6 billion). New investments were expected to lead to a total chemical labour force of 20,000 in the region.

was developed because there was a need for rational consumption of steam by the Statoil refinery. In exchange for steam, the refinery sends its effluent cooling water to a coal-fired power plant as boiler feed (Planète Énergies 2016). Box 4.2 describes the Shanghai Chemical Industry Park.

#### Challenges and policy opportunities related to chemical industrial parks

A number of challenges exist in establishing chemical parks and mobilizing investors and businesses. Apart from difficulties with the mobilization of initial investments, companies may, for example, not be convinced they will receive a reasonable return when they invest in related upgrades, renovations, more efficient processes, or changes in business practices. They may also be concerned about information sharing with potential competitors (LeBlanc *et al.* 2016). Another challenge for a chemical park operator is to attract new companies. Other barriers relate to technological development and capacity building. However, promoting cooperation among stakeholders though active involvement by policymakers can help overcome these barriers (Zhu *et al.* 2014).

## 4.4 Customer-centric business models

The development of customer-centric business models is an important dimension of Industry 4.0 (or the Fourth Industrial Revolution) (Renjen 2018). These models involve a better understanding of customer needs and wants, as well as ensuring that the right strategies, processes and marketing initiatives are in place to satisfy them (Kroner 2014). A customer-centric model is built around a deep understanding of customers, what they value, and the contribution each makes to a company's profitability. This includes delivering a positive and seamless customer experience at every touch point across the customer life cycle, maintaining active dialogue with customers, and fostering a culture that puts the customer at the heart of the decision-making process (EY 2013). It may also involve more direct marketing and sales operations to reach consumers faster and more efficiently.

### 4.4.1 Additive manufacturing/3-D printing

#### The rise of additive manufacturing/3-D printing

The development of advanced manufacturing technologies, and growing consumer demand for more customized products and services, are bringing about significant changes in the scale and distribution of manufacturing (Ford and Despeisse 2016). 3-D printing, also known as additive manufacturing, is a consumer-centric business model with the potential to revolutionize production processes. It has important implications for the chemical industry. 3-D printing replaces traditional manufacturing, in which products are manufactured at a company's main production facility and shipped elsewhere. An additively manufactured product is printed layer by layer, with each cross section stacked on top of the one below it. This is done without using large, high-throughput machinery, and at


hundreds or thousands of remote locations, with near-zero waste (Phansey 2014).

By "democratizing" manufacturing, 3-D printing allows small fabrication businesses to reduce labour costs and offer manufacturing services close to the point of need. Service-oriented businesses are evolving which offer libraries and exchanges for 3-D printable digital blueprints; services to transmit these blueprints; and services for networking of 3-D printers (Duffy 2016). 3-D printing avoids the need to invest in producing moulds, which requires large product orders to achieve scale. This is of special significance for small and medium-sized manufacturing firms (Wayne 2017).

In light of these opportunities, the global additive manufacturing market is expected to grow to more than US dollars 6 billion by 2022, with a compound annual growth rate of more than 13 per cent between 2016 and 2022 (Market Research Engine 2017). Apart from providing more customer-centric solutions, 3-D printing provides significant economic and environmental benefits. It is estimated that it will reduce costs by US dollars 170-593 billion, primary energy supply by 2.54-9.30 exajoules, and $CO_2$ emissions by 130.5-525.5 megatonnes by 2025 (Gebler, Schoot Uiterkamp and Visser 2014).

3-D printing technology has significant potential for developing countries, as the cost of printers is falling below US dollars 500 (Ibrahim *et al.* 2015). 3-D printing has the potential to contribute to economic empowerment and improve the livelihood of communities in developing countries by providing opportunities to design and create tools that support and improve people's daily lives (Ishengoma and Mtaho 2014). A growing number of non-profits are promoting and supporting the use of 3-D printing technology in developing countries (Molitch-Hou 2014).

### What does 3-D printing mean for chemicals and waste management?

Chemical companies are already developing a range of plastics and resins, as well as metal powders and ceramic materials, for printing prototypes of products, industry parts and semi-finished goods. 3-D printing, as a consumer-centric business model, provides significant opportunities for the chemical industry through, for example, developing innovative feedstocks, printing lab equipment, and maintaining plant assets (Guertzgen 2017). It also provides opportunities to use waste materials such as plastics as raw material for 3-D printing (Walker 2017). Moreover, 3-D printing can enhance design flexibility for chemical equipment, for example with unique designs for modular distillation columns (Mardani *et al.* 2016) and packing for rotating packed beds (Gładyszewski and Skiborowski 2018).

3-D printing can improve efficiency and reduce the time required to manufacture individual batches. For example, a maker of invisible braces has used 3-D printing to increase batch size and reduce the time required to run each batch. The company also requires less space compared with its traditional manufacturing method (Pullen 2014). In addition, plastic waste can be turned into 3-D printing filament, so that 3-D printing becomes a viable means of consuming waste plastics (Kreiger *et al.* 2014; Mohammed *et al.* 2017).

Researchers have designed a 3-D printer to synthesize pharmaceuticals and other chemicals from simple, widely available starting compounds fed into a series of water bottle-sized reactors. This technology could one day enable consumers to 3-D print their own drugs (Service 2018). The technology also enables the manufacture of medications that rapidly disintegrate with a sip of liquid even at high doses, which could help people who have difficulty swallowing pills (Crawford 2015).

### Potential health and environment concerns

Despite its significant potential, 3-D printing may also pose risks. Concerns have been expressed, for example, about material use, exposure and emissions (European Agency for Safety and Health at Work 2017). While in general additive manufacturing is considered environmentally preferable to conventional manufacturing, because of its potential for local production and nearly zero-waste manufacturing, research indicates that environmental performance depends on patterns of use, the configuration of the 3-D printer and the materials used (Yale School of Forestry & Environmental Studies 2017). 3-D printing can therefore have varying environmental impacts; for example, the use of polylactic acid (PLA) bioplastic consumes less energy than the use of acrylonitrile butadiene styrene (ABS) plastic (Faludi *et al.* 2015).

Many kinds of 3-D printing machines exist, but not all of them can be operated waste-free. An inkjet 3-D printer wastes, for example, 40-45 per cent of its ink (the portion that is not recyclable) (Faludi 2013). Also of concern is that 3-D printers often use non-environmentally friendly ABS plastics, nylons and other non-recyclable materials and post-processing chemicals that can create toxic fumes. Moreover, it has been shown that these printers can emit ultrafine particles or volatile organic compounds (VOCs). Caution should therefore be used when operating printers and filament combinations in poorly ventilated spaces, or without the aid of combined gas and particle filtration systems (Azimi *et al.* 2016). In addition, strategies for safe disposal of 3-D printed parts and printer waste materials are needed (Oskui *et al.* 2016). There are also concerns that 3-D printing could lead to renewed materialism, with consumers driven to print more, encouraging a culture of consumption and disposal (March 2015).

## 4.4.2 e-commerce: selling chemicals online

### Business-to-business e-commerce websites

Chemical distribution is evolving rapidly, with a growing number of companies and distributers selling chemicals online. In addition, e-commerce is a new way for small and medium-sized chemical distributors to reach existing and potential customers (Independent Chemical Information Service [ICIS] News 2016). Amazon Business, for example, is a business-to-business (B2B) platform that allows registered businesses to shop for office, janitorial and industrial goods online and obtain volume discounts. One chemical company engaged in e-commerce is BASF, which in mid-2015 opened its first e-commerce store in China using the Alibaba B2B marketplace platform. Its goal was to make the company's products and services more accessible to small and medium-sized enterprises (SMEs) (Ling and Pflug 2015). BASF later announced it would establish a flagship online store, along with other major chemical companies such as Covestro, on Alibaba's B2B platform, 1688.com (ICIS Chemical Business 2018). Specialty chemical companies have launched their online stores on the same platform to provide an easily accessible procurement process (Evonik 2017; Solvay 2018).

### E-commerce platforms selling to consumers

Online shopping platforms selling to consumers, such as Alibaba, Ebay and Amazon, are growing rapidly. Consequently, an increasing number of hazardous chemicals may find their way onto markets. Some of the major e-commerce

platforms have hazardous chemical policies. Alibaba has a "Flammable, Explosive and Hazardous Chemicals" policy which prohibits the posting of explosives, radioactive or poisonous chemicals, ozone-depleting substances and other harmful substances. Purchasing such materials could lead to delisting of the poster's account (Alibaba 2018). Under Amazon's "Hazardous and Dangerous Items" policy, users are prohibited from listing items for sale that contain bisphenol A, carbon tetrachloride and red phosphorus, explosive substances, products contaminated with radiation, mercury products and refrigerants, among others (Amazon 2018). Ebay has a "Hazardous, restricted or regulated materials policy" which lists items that cannot be advertised on its website, the violation of which could lead to removal of the listing and suspension of accounts (Ebay 2018).

### Challenges

Despite these policies, little is known about the extent to which e-commerce platforms have chemical policies and, if so, whether these policies are compatible with regulatory requirements. There are also questions about which jurisdictions guide (or should guide) the chemical policies of e-commerce platforms, and how the selling companies can effectively monitor compliance or violations. To illustrate the challenges, under the European Chemicals Agency's (ECHA) enforcement scheme 1,314 internet advertisements were checked for hazardous chemical mixtures, of which 82 per cent were found to be non-compliant with the EU's Classification, Labelling and Packaging (CLP) regulation (Stringer 2018). If a company sells chemicals online in several regions, it is important for the company to know and follow all the rules and regulations for each region, as chemical products and the selling of them are subject to different rules in different countries (Clarity 2015).

## 4.5 Social entrepreneurship business models

### Social enterprise: a model for change

The purpose of a social enterprise combines revenue growth and profit-making with respect and support for its environment and stakeholder network (Agarwal *et al.* 2018). Social enterprises lie at a point of convergence between the non-profit and for-profit spheres, combining the social orientation and objectives of NGOs with the market-driven practices of businesses. A social enterprise does not do social good to improve its image or regard this as a means to increase sales. Rather, it pursues social objectives and uses business approaches to attain these objectives (Panum and Hansen 2014). A social enterprise business model is essentially driven by a social mission, generates positive externalities for society, and recognizes the centrality of the entrepreneurial business function (Bocken *et al.* 2014).

Social enterprises create economic value as a tool to achieve social goals (Perrini and Vurro 2006). Profit is seen as a tool for advancing sustainability. In this way, enterprises move away from grant dependency to become self-sufficient through the creation of income streams (Panum and Hansen 2014). Social Enterprise UK, in its State of Social Enterprise Survey 2015 (Villeneuve-Smith and Temple 2015), found that the social enterprise movement was growing rapidly, with a greater proportion (40 per cent) of social enterprises increasing their turnover as compared to mainstream SMEs. This growth is driven by the increasing power of the individual (especially millennials), a shift to greater trust of businesses, and technological change and advancement (Agarwal *et al.* 2018).

Social enterprises address a range of social issues. These include social and environmental issues with direct or indirect links to chemicals and waste management. A social enterprise addressing the problem of plastic waste in Kenya through recycling is described in Box 4.3.

How do we know whether an enterprise contributes social and environmental value?

**Box 4.3** **Ocean Sole: a social enterprise in Kenya (Panum and Hansen 2014)**

Ocean Sole is a social enterprise operating in Kenya. The founder, Julie Church, was appalled by the vast amount of plastic flip-flops washed up on shore in northern coastal Kenya, disturbing marine life. This gave her the idea of collecting the flip-flops and recycling them into crafts, facilitating the employment of local unemployed women as a workforce. Ocean Sole started with the proposition of creating environmental and social value through the collection and recycling of flip-flops and through environmental awareness-raising in local communities, as well as among the eventual consumers. Embedded in this value proposition is education of the public, together with nudging its behaviour towards using recycled products.


© Ocean Sole Africa , one of Ocean Sole's products

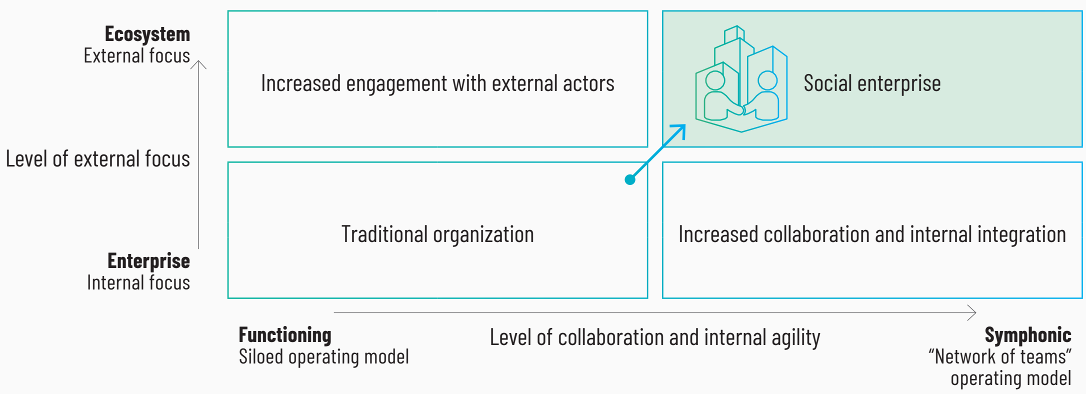
The business model of Ocean Sole is effectuated through three main phases: collection of the flip-flops, recycling, and sale. The process is as follows:

Collection of flip-flops > washing and disinfecting > drying > gluing > crafting > sale

The crafts are sold in shops in and around Nairobi, in retailer outlets in Kenya, and internationally.

The Social Enterprise Mark is an example of an international social enterprise accreditation scheme that enables social enterprises to demonstrate they are making a difference. It independently guarantees that a business's central aim is to use its income and profits to maximize positive social and/or environmental impacts, and that this takes precedence over maximizing personal profits for owners and shareholders (Social Enterprise Mark CIC 2018). Figure 4.5 shows the evolution of the social enterprise.

**Figure 4.5** **Evolution of a social enterprise (adapted from Agarwal *et al.* 2018, p. 3)**



### Social enterprises may fill gaps in governance

Social enterprises have the potential to support and build on government initiatives (Ding 2017). They may also fill gaps when governmental action is lacking. They can have significant impacts in countries with low levels of state capacity to address social problems. From a government perspective, collaborating with social enterprises can result in short- and long-term gains for public budgets through reduced public expenditure and increased tax revenue (OECD and EC 2013). If such benefits are identified, enabling government institutions, resources and policies may be used to scale up social enterprises, including through partnerships with local governments (Shockley and Frank 2011).

### Social enterprises' contributions to chemicals and waste management

Social enterprises that address chemicals and waste management issues, directly or indirectly, are emerging in many countries. For example:

- A Melbourne, Australia, social enterprise called *Green Collect* gathers hard-to-recycle waste and employs socially disadvantaged people to refashion it into useful items to sell back to the companies that threw it out (Smith 2016).
- *Wecyclers*, a waste management social enterprise in Lagos, Nigeria, encourages households to collect and turn in waste. They receive "Wecyclers points" that can be used to buy household goods and services. Wecyclers sorts and aggregates the collected materials and sells them to local recycling processors (Okeugo 2015).
- *TackleTox* is a social enterprise that displays, on a map, information about toxic chemical substances emitted by corporations. It currently provides toxic scores for over 28,000 facilities in both the Republic of Korea and the United States (Yoon 2018).
- *Fairphone* is a social enterprise that aims to make smartphones in a modular way, so they can be easily repaired and upgraded over a longer period of use. It also avoids using minerals mined in conditions of armed conflict and human rights abuses (Keizer *et al.* 2016). Fairphone works with its partners to set up projects in Ghana to improve local waste collection efforts and transport discarded phones to Europe for safe recycling. Fairphone's Take Back Program helps ensure that old mobile phones are reused or properly recycled (Fairphone 2016).
- Code Enterprise LLP is India's first cigarette waste management and recycling firm. It operates in 20 states and has already recycled 4 tonnes of cigarette butts into useful products. A chemical process is used to recycle discarded cigarette butts into clean cellulose acetate, the polymer used in the butts. By-products can also be used for plantations and nurseries. The recycled polymer material is used to make cushions, garlands, small stuffed toys, accessories and key chains (Roy 2018).

### Challenges and opportunities

When they start a social enterprise, most entrepreneurs face challenges in securing funding and investment capital. Locating the right manufacturer or supplier is another challenge for product-based social enterprises (Muhammed 2018). Still another challenge is mission drift, as a result of which enterprises abandon their social concerns in favour of profit-seeking activities. This can cause internal conflict and lack of support from stakeholders. It is therefore important for companies to avoid or rebalance mission drift (Ramus and Vaccaro 2017).

Governments in a number of countries use policy tools such as fiscal incentives, grants, awareness campaigns and incubation to encourage social enterprises (Sanchez 2016). For example, in the United Kingdom social investment tax relief (SITR) has been introduced. SITR encourages individuals to support social enterprises and receive a tax deduction equal to 30 per cent of their investment (Government of the United Kingdom 2016). In India, the Maharashtra State Social Venture Fund aims to invest in profitable and scalable business ventures with the potential to provide social benefits to the people of Maharashtra (SIDBI Venture Capital n.d.).

## 4.6 Potential measures to advance the sustainability of business models

New and evolving business models, such as service-oriented models (Chemical Leasing) and models for benefit coordination (e.g. chemical parks), as well as social enterprises, can create opportunities to advance the chemicals and waste management agenda. Other models (e.g. 3-D printing and e-commerce) are also evolving rapidly and will benefit from careful scrutiny. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to advance the sustainability of business models:

- Promote service-oriented chemicals management approaches, such as Chemical Leasing, to enhance resource efficiency and decrease use of hazardous chemicals.
- Use chemical parks as a model for sharing services, learning and information among companies, including SMEs.
- Explore the role and stimulate the establishment of social enterprises to support the sound management of chemicals and waste at all levels
- Review the chemistry dimension of 3-D printing/additive manufacturing and take measures to reap its full potential by managing potential risk early on.
- Take measures to ensure that the distribution of chemicals through e-commerce meets high standards of chemical hazard communication, and is fully compliant with relevant legislation.

# 5/ Fiscal incentives to advance sound chemicals management and sustainable chemistry

## Chapter Highlights

The use of market-based instruments to manage hazardous chemicals and waste is limited, but increasing.

Market-based instruments can effectively complement command and control regulatory measures, such as bans or restrictions.

Market-based instruments create incentives for cost-effective substitution and can spur innovation.

Reforming subsidy programmes that provide perverse incentives is often a challenge.

Careful design, evaluation and flexibility are needed to adjust instruments to market reactions.

Political economy considerations are important when implementing market-based instruments

Fiscal incentives are government policies that change the relative price of a given activity or input, either encouraging or discouraging its use. This chapter takes stock of the extent of, and lessons learned from, the use of fiscal incentives for chemicals management. It discusses the effectiveness, benefits and challenges of market-based instruments, within the broader array of possible policy instruments in the context of chemicals and waste management.

## 5.1 Market-based instruments as an important complement to bans and use restrictions

### Many market-based instruments can be used to create fiscal incentives for sound chemicals management

A wide range of market-based instruments are used in chemicals management (Table 5.1). They stimulate behavioural change by providing price signals to chemical producers and manufacturers, downstream users, consumers and waste management agents, among others. Incentives can be created by removing existing price distortions that generate perverse incentives for overuse, or by implementing new market-based instruments such as taxes, charges, deposit-refund systems, subsidies and tradable permits. The level of taxes and charges should ideally

**Table 5.1** **Types of market-based instruments and examples of their application to chemicals management (based on Stavins 2001; Sterner and Coria 2011; OECD n.d.)**

| Policy instrument | Description | Example of application |
|---|---|---|
| Tax | By increasing the price of using a chemical, a tax incentivizes decreased use. Typically levied by the state, with its proceeds going to the general budget. The level should reflect the damages caused by production, use and/or disposal of the chemical, which in the absence of the tax would not be reflected in the market price. | Pesticides; inorganic fertilizers; chlorinated solvents; batteries |
| Charge/fee | Similar to a tax, but revenues are typically earmarked. The level of a fee should reflect the cost of providing a specific service, such as processing hazardous waste. | Hazardous waste; pesticide or chemical containers; tyres; batteries |
| Subsidy | A subsidy is the mirror image of a tax. It can provide incentives to increase the use of alternative chemicals that are less hazardous. In particular, authorities may want to subsidize learning and technology development. | Subsidies for organic farming; lead paint removal |
| Subsidy removal | In many cases subsidies are used without giving sufficient attention to their distribution, potentially resulting in unsound practices from a health or environmental perspective. Hence, subsidy removal is considered a policy instrument in its own right. | Removal of subsidies for use of chemical fertilizers or pesticides |
| Deposit-refund | A surcharge is paid when potentially polluting products are purchased. A refund is received when the product is returned to an approved centre, whether for recycling or for disposal. | Pesticide or chemical containers; batteries; tyres |
| Tradable permits | An overall level of "allowable" pollution is established and allocated among firms in the form of permits. These permits can be traded on a market at market prices. | Lead in gasoline (trade among refineries); ozone-depleting substances (trade among producers and importers) |

be set so that all externalities (i.e. the full cost to society from production, consumption and disposal of targeted chemicals of concern, or products that include such chemicals) is reflected in their price (Sterner and Coria 2011).

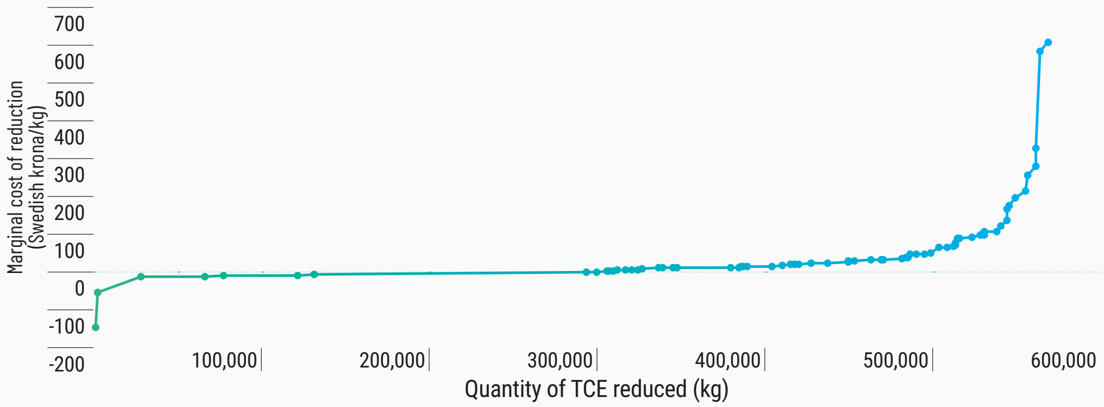
### Market-based instruments can create incentives for cost-effective substitution and spur innovation

The two main arguments in favour of fiscal incentives are that they can be more cost-effective, and better at promoting innovation, than bans, use restrictions or technology standards. These command and control policies (commonly used

**Box 5.1** **Shifting taxes from labour to resource use and pollution (Groothuis 2016)**

Achieving sustainability is affected by a number of factors They include efficient use of resources, closing material loops, reducing (toxic) waste, reclaiming waste as raw material, and designing materials and chemicals that fit these purposes. An independent Dutch think tank researched a possible shift of taxation of labour to pollution, use of resources and consumption. In the Ex'tax Policy Toolkit they presented a suite of tax base options through which such a shift can be designed, covering topics such as building materials, food production, metals and minerals, and waste. Key findings of the research were that a shift in taxation would result in increased GDP, create jobs, and cut emissions and pollution. This shift incentivizes sustainable business models and innovation, including in the chemical sector, given an increase of the cost of water, harmful emissions, metals and minerals through systematic application of the polluter pays principle. Moreover, reductions in labour costs, combined with increased resource and pollution costs, are expected to support labour-intensive R&D efforts, repair, maintenance and collection of waste, thus stimulating ecological product design.

**Figure 5.1** Marginal cost of reducing the use of trichloroethylene (TCE) in metal degreasing (adapted from Slunge and Sterner 2001, p. 292)






The marginal cost of reducing the use of TCE (or replacing its use altogether) in metal degreasing were reported by 65 companies in Sweden. For most companies the marginal costs were relatively low, but some reported that it would be very costly to reduce TCE use.

in chemical risk management) typically allow very little flexibility in regard to the means of achieving specific targets (Stavins 2001). Instead, all firms must meet the same target no matter how costly the change. However, the cost of complying with a ban or use restriction often differs between companies. This may be due to differences in, for example, production processes and sunk costs from technology investments. Figure 5.1 provides an example of differences in the marginal costs of reducing the use of trichloroethylene (TCE) in metal degreasing.

Companies have an incentive to substitute the targeted chemical as long as the marginal cost of substitution is lower than the cost of using the targeted chemical. By allowing firms with different substitution costs to reduce use on different time scales, market-based instruments can incentivize a cost-effective reduction in the use of the targeted chemical. Moreover, by increasing the cost of using a specific chemical, taxes and charges can spur innovation and the search for new alternatives. Innovation can be further incentivized if tax proceeds are invested back into the search for cleaner, less harmful substances.

## Market-based instruments complement rather than replace bans and use restrictions

While market-based instruments have some merits, there are many situations in which their use is less appropriate. For example, when the health and environmental costs of exposure to a hazardous chemical are very high, the effects are location-specific or threshold effects are likely. In such situations bans and use restrictions are more appropriate (Weitzman 1974). In practice, many context-specific factors (e.g. information constraints, administrative costs, distributional effects and political economy pressures) determine which policy instruments are most effective and feasible to implement. Policy instrument design therefore needs to be context-specific.

In many cases it can be beneficial to combine market-based instruments with restrictions on exposure to hazardous chemicals. Introducing a tax or charge which creates incentives for substitution and innovation can make it easier to implement tougher use restrictions or even bans at a later stage. Transparency, and access to information on the use of chemicals and its associated effects, are often prerequisites for effective design and implementation of market-based instruments.

**Box 5.2** **Risk-based pesticide taxation in Norway and Denmark**

In Norway a new taxation scheme for pesticides (plant protection products) was introduced in 1999. Pesticides were classified in different risk groups, with higher taxation for higher risk categories. Figure 5.2 indicates that a shift towards using pesticides that were relatively less hazardous resulted. A difficulty with classifying pesticides into distinct risk categories is that those with similar levels of environmental and health risks may show big differences in their tax rates if they are at the bottom or top of their respective risk categories. An alternative pesticide taxation scheme was introduced in Denmark in 2013. Under this scheme, the tax level for each approved pesticide was calculated based on its human health risks and environmental characteristics. Instead of distinct risk categories, the tax level was based on an environmental load index ranging from 0 to 40. There was considerable difference in the tax levels, which ranged from euros 0.57 to euros 25.5 per hectare. The new pesticide taxation scheme was projected to play a major role in achieving the government's objective of reducing the total quantity of pesticides applied by 40 per cent between 2013 and 2015 (Böcker and Finger 2016). Preliminary evaluations indicate that this objective was met (Ørum, Kudsk and Jensen 2017). Pesticide taxation in Norway and Denmark is combined with tax exonerations for farmers who fulfil specific requirements regarding pesticide management and observe other use restrictions.

## 5.2 Experience with using market-based instruments in key industry sectors

### Use of fiscal incentives to manage hazardous chemicals: limited but increasing

Compared with other policy areas, the use of market-based instruments in chemicals management is relatively limited. Market-based instruments are mainly used in high-income countries, but a number of low- and middle-income countries have also begun to use them, particularly in relation to hazardous waste management and reducing the use of plastic bags. In many cases where market-based instruments have been used for chemicals management, formal evaluations of their effectiveness are lacking. The cases presented below illustrate some applications, as well as problems that policymakers face in designing policy instruments.

### Taxing pesticides to reduce environmental and health risks

Several countries, including Denmark, France, Norway and Mexico, have begun to use differentiated taxation of pesticides (mainly plant protection products) to incentivize farmers to reduce the use of hazardous pesticides (Box 5.2 and Figure 5.2). Factors taken into account in determining the taxes include, for example, hazard properties, health risks, environmental

**Figure 5.2** Effects of differentiated taxation on quantities of pesticides sold in Norway, 1997-2008 (adapted from Kjäll 2012)


Under the taxation scheme for pesticides (plant protection products) introduced in Norway in 1999, pesticides were divided into five risk groups with higher taxation for higher-risk groups. A shift towards using more of the relatively less hazardous pesticides took place.

load or environmental harm, depending on the country. Recent evaluations have found evidence that taxation which is linked to hazards and risks can be effective in reducing pesticides' environmental and health effects. In contrast, non-differentiated taxation of pesticides (e.g. through ad valorem or per unit taxes) can have unintended consequences, as quantity reductions may be achieved through substitution with more toxic products (Finger *et al.* 2017). Closer proportionality of taxes to reduce environment and health risks may also increase the chance that a tax is perceived as fair. Such taxation may not only enhance the economic desirability of taxes, but also increase their political legitimacy (Söderholm and Christiernsson 2008).

### Reforming subsidy programmes which create perverse incentives is often difficult in practice

Many countries provide substantial subsidization of agrochemicals in order to promote agricultural production and increase food security. However, these subsidies can have severe negative environmental effects and they imply a high fiscal burden. The nature of the environmental effects

**Box 5.3** The fertilizer subsidy programme in India

To incentivize agricultural production, the central government in India subsidizes the use of chemical fertilizers. This has played an important role in increasing grain production. However, the cost to the government of keeping fertilizer prices below the market price has increased dramatically since the subsidy programme was introduced in the late 1970s. In 2015 the cost of fertilizer subsidization was estimated at approximately US dollars 12 billion.

There is limited evidence concerning this programme's environmental effects. It can be shown that the programme has led to imbalanced use of nutrients by farmers through keeping the price of urea (an inexpensive form of nitrogen fertilizer) at a very low level. Excessive and imbalanced use of nutrients has contributed to soil degradation and water pollution (Gulati and Banerjee 2015). A key challenge in reforming the programme is that many farmers are financially dependent on these subsidies (Praveen *et al.* 2017).

**Box 5.4** **Chemical taxes on consumer products in Denmark and Sweden**

Responding to growing concerns about risks from cumulative exposure to hazardous chemicals in consumer goods, in 2000 Denmark introduced a tax on products containing PVC and phthalates. The rate was approximately euros 0.3 per kilogram of PVC and euros 0.9 per kilogram of phthalate, with some variation depending on the product. As part of broader tax reform, the Danish government decided to abolish this tax in 2019. The effects of the tax are uncertain (Stringer 2017). An early assessment pointed to a 15 per cent decrease in the use of phthalates between 2002 and 2004 (Government of Denmark 2006). The rate has not changed or been adjusted for inflation since the tax came into effect. European regulations on phthalates have since been introduced.

Sweden introduced a tax on certain chemicals in electrical and electronic products in 2017. Producers and importers of these products pay an excise duty of around euros 0.8 per kilogram for kitchen appliances and euros 0.12 per kilogram for other electronic products. There is a maximum amount of euros 32. per item. If producers and importers can prove that electronic products do not contain additive compounds of bromine, chlorine or phosphorus, they can obtain a 50 per cent tax deduction. If they can also show that the products do not contain reactive added bromine or chlorine compounds, a deduction of 75 per cent is allowed. Since the tax recently came into force, it has not yet been evaluated. However, it has been criticized by industry for not being based on comprehensive risk assessment and for being administratively burdensome.

depends on how the subsidy programme is designed and on site-specific agroenvironmental conditions. This makes it difficult to carry out a general environmental assessment of the benefits of agricultural subsidization.

Reducing or removing subsidies is often difficult, as they tend to encourage lobbying by beneficiaries in order to protect and prolong the subsidies. Box 5.3 describes the fertilizer subsidy programme in India.

### Market-based instruments can be used at different stages in the chemical life cycle

Market-based instruments are applied at different stages of the chemical life cycle. For example, in the United States chemical producers and manufacturers took part in schemes with tradable permits to incentivize refineries to phase out lead in gasoline in 1982-1987, and in the phase-out of ozone-depleting substances in the early 1990s (Harrington, Morgenstern

**Box 5.5** **Different effects of charges on plastic bags in Ireland and South Africa**

Charges have been used in several countries to reduce demand for plastic bags. The primary purpose has been to reduce plastic littering. The effects of these charges are mixed. A charge of euros 0.15 per bag, introduced in Ireland in 2002, led to a 90 per cent reduction in use and reduced littering (Convery, McDonnell and Ferreira 2007). Similarly, in South Africa the charge of around euros 0.05 (rand 0.46) introduced in 2003 led to an estimated 90 per cent reduction in demand for plastic carrier bags. However, after pressure from manufacturers the charge was lowered after only three months and demand for the bags increased again (Dikgang, Leiman and Visser 2010). In Ireland, besides the effect of the charge on demand, extensive stakeholder consultations and information campaigns conducted in relation to the plastic bag charge contributed to the effectiveness of the policy instrument. In South Africa the revised charge was too low to affect demand. Since 2015, large retailers in England have been required by law to charge 5 pence (around euros 0.06) for single-use plastic carrier bags. The seven main retailers issued around 83 per cent fewer bags (over 6 billion bags fewer) in 2016-2017 compared to the calendar year 2014. This is equivalent to each person in England using around 25 bags in 2016-2017, compared to around 140 bags per year before the charge (United Kingdom Department for Environment, Food & Rural Affairs 2018).

and Sterner 2004). The Norwegian tax on trichloroethylene and perchloroethylene from 2000 is an example of chemicals used in the metal manufacturing industry and dry-cleaning facilities being targeted (Slunge and Sterner 2001). Taxes on phthalates, polyvinyl chloride (PVC) and flame retardants introduced in Denmark and Sweden are examples of taxes targeting consumer products where it is the importer or product seller who pays the tax (Box 5.4) Taxes and/or fees on plastic bags used in Ireland, South Africa, the United Kingdom, the United States and a number of other countries are examples of those paid by consumers (Box 5.5). In Canada, Loblaw Companies Limited has estimated that its voluntary 5 cent fee on plastic bags prevented the use of 11 billion bags in Canada subsequent to its launch in 2007. Proceeds are donated to an environmental organization (Loblaw Companies Limited 2017, p. 11).

### Charges and refunds used to finance hazardous waste management

Charges and deposit refund systems are frequently applied in the management of hazardous wastes such as batteries, end-of-life vehicles, and waste electric and electronic equipment. These instruments can both incentivize reduced use of, for example, batteries containing hazardous chemicals, and finance systems for the collection and processing of hazardous waste. Box 5.6 describes how a charge on waste electric and electronic equipment (WEEE) is used to finance hazardous waste management in China.

In many countries the establishment of extended producer responsibility (EPR) systems has shifted the cost of waste management from authorities to producers and greatly increased the rate of recycling of different waste categories. A provincial EPR programme for tyres across Canada, for example, increased the rate of collection to ~90 per cent, and largely eliminated the stockpiling and burning of end-of-life tyres countrywide (Canadian Association of Tire Recycling Agencies 2018). However, little effect has been seen on product design. Costs to producers are often not directly connected with their own products, while insufficient collection further lowers the incentive for eco-design (Kalimo *et al.* 2015; Turner and Nugent 2016; Zeng *et al.* 2017).

**Box 5.6 The waste electric and electronic equipment (WEEE) recycling fund in China**

Several areas in China have been severely polluted due to crude methods of WEEE recycling in an uncontrolled informal sector. To help create a regulated formal sector for safe WEEE recycling, the WEEE Processing Fund Collection and Subsidy Management Approach was introduced in 2012. Producers and importers pay a charge based on annual sales and product type. Revenues are placed in a government fund which is used to support formal dismantling companies (Gu *et al*. 2017). The fund system effectively reduced the informal sector for the original five product groups and established a formal sector consisting of more than 100 licensed enterprises (Zeng *et al.* 2017). However, the fund is financially imbalanced, as subsidies to the formal enterprises are five to 10 times higher than the fee charged to producers and importers of electric and electronic products (Gu *et al*. 2017; Zeng *et al*. 2017).

## 5. 3 Context-specific design of market-based instruments is critical for their effectiveness

### Careful design, evaluation and flexibility are important in order to adjust to market reactions

Optimally, a "green tax" should be set such that the marginal damage is equal to the marginal benefit of using the chemical. From the point of view of economic efficiency, it is desirable to target policy instruments to specific environmental or health damage as closely as possible. The risk of restricting the use of chemicals that do not cause negative health and environmental effects is thereby reduced. The design of a particular policy instrument also needs to carefully consider technical and political complications associated with the distribution of the regulatory costs and benefits that result from targeting actors at different stages of the chemical life cycle (Söderholm 2009; Coria 2018).

Good knowledge of context-specific factors such as price elasticities, market structure, availability of substitutes, and exposure characteristics for regulated hazardous chemical facilitates the choice and design of policy instruments. However, in many cases there is a lack of data, and assessments based on existing data are often surrounded by considerable uncertainties. There is a need for careful data collection, monitoring and evaluation of the performance of different policy instruments for chemicals management. Flexibility to adjust tax levels after observing market reactions is also necessary.

Balancing the benefits of a targeted approach against its transaction costs is a key dilemma in policy instrument design (Vatn 1998). It may be difficult or impossible to acquire the needed information on the production of the chemical itself, so that those planning such an approach would typically move up the life cycle, for example taxing use of the chemical as an input to the production of other goods and services. However, in some cases information on the production of other goods and services is hidden or private and the regulator is forced to use taxes and similar instruments based on final disposal of the chemical. This is the case for non-point pollution, where the regulator can only observe final pollution levels in the aggregate.

### Political economy considerations are important when implementing market-based instruments

The introduction of market-based instruments for chemicals management often faces resistance from interest groups which will pay higher taxes or will no longer benefit from a subsidy. Consultation and monitoring of stakeholders' reactions to a newly created incentive are important in order to help avoid undesired side effects and ensure that incentives operate at the right level. How information on policy change is communicated (and how revenues are used) are often critical to successful implementation.

## 5.4 Potential measures to scale up the use of fiscal incentives

The use of market-based instruments has the potential to effectively complement regulatory approaches to advance the sound management of chemicals and waste. Further international research and knowledge sharing could help to reap the full potential of these instruments. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to scale up the use of fiscal incentives to advance sound chemicals management and sustainable chemistry:

- Expand the use of differential taxation of hazardous chemicals, based on lessons learned from recent hazard- and risk-based taxation.
- Evaluate and address the effects of subsidies and other policies that can generate perverse incentives which increase use of hazardous chemicals in agriculture and other sectors.
- Use charges to speed up the phasing out of substances of very high concern.
- Evaluate the use of market-based instruments for groups of chemicals, based on the precautionary principle applied to the identified hazards of the active ingredients in similar chemicals (e.g. taxes on flame retardants and phthalates).
- Use legal requirements for Extended Producer Responsibility, environmental liability and access to information in order to incentivize sound chemicals management, in line with the polluter pays principle.
- Establish a policy learning process through systematic monitoring and evaluation of the effectiveness of policy instruments for chemicals management in different sectors and contexts.

# 6/ Sustainable supply chain management for chemicals and waste in the life cycle

## Chapter Highlights

A number of retailers, product manufacturers and companies in the chemical industry have taken measures to include sustainability in their procurement processes.

Identifying and sharing information on chemicals in products, and their human and health impacts in the life cycle, are important but challenging.

Industry action to advance the flow of information in the supply chain on chemicals, and products that contain chemicals, is gaining momentum, although gaps remain.

The recycling sector, which has a key role to play in advancing non-toxic material flows and circularity, needs to have appropriate knowledge about the chemicals in its supply chain.

Sustainable supply chain management is essential in ensuring that procurement decisions comply with sustainability criteria and create a force driving upstream suppliers.

While the generation of relevant data and knowledge is valuable, green and sustainable chemistry principles can already be applied in the design of new products.

The complexity of global value and supply chains and the increasing trade in chemicals and products (discussed in Part I) create both the need and opportunities for key actors in the supply chain to understand and take action with respect to chemicals and products throughout the product life cycle. This chapter focuses on sustainable supply chain management. It provides both a conceptual discussion and examples from key actors in the value chain, in order to enhance the flow of information and sustainability considerations within the supply chain.

## 6.1 Drivers for sustainable supply chain management

### From supply chain risk management to sustainable supply chain management

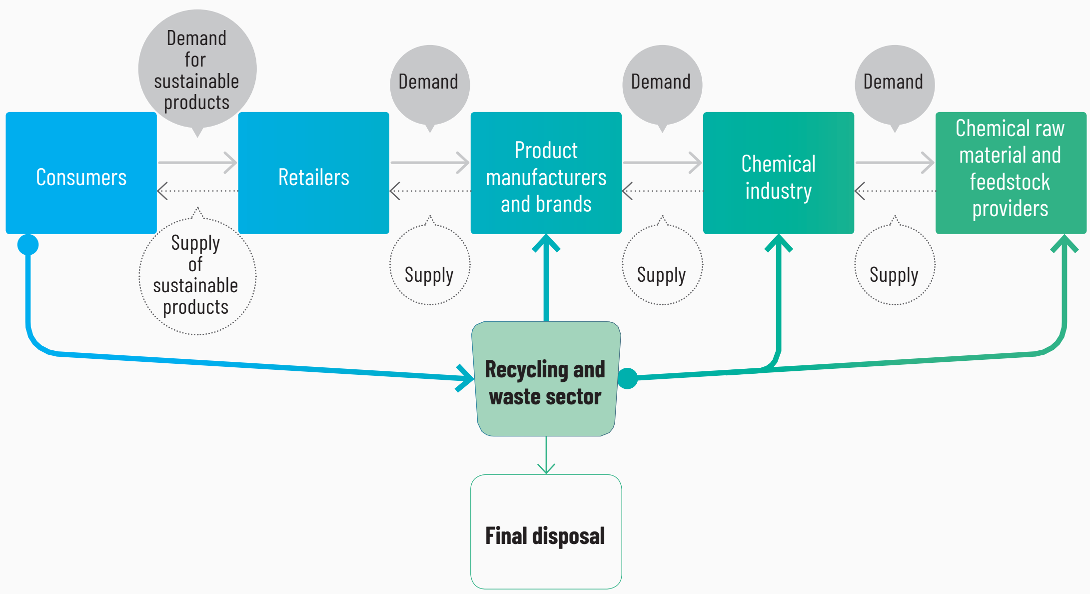
Companies have traditionally focused on managing technological and economic risks that occur along their supply chains though supply chain risk management (SCRM) strategies. Supply chain risk may be defined as "the likelihood and impact of unexpected macro and/or micro level events or conditions that adversely influence any part of a supply chain leading to operational, tactical, or strategic level failures or irregularities" (Ho *et al.* 2015). However, the image of a company – large- or small-scale - is not only related to its economic performance, but also to its environmental and social behaviour and impacts. These may include impacts caused by its suppliers and sub-suppliers in the supply chain (Leppelt *et al*. 2013). Certain companies in the pharmaceutical sector, for example, have been held responsible for the environmental conduct of some of their suppliers (Fick *et al*. 2009).

It makes business sense for companies to know as much as possible about the chemicals in their products and supply chains. There are costs companies may eventually have to pay for not knowing about, or not acting on, harmful chemicals in their products and supply chains, whereas they could reap benefits through managing chemicals safely. Nevertheless, most product sectors do not have sufficient information systems in place to ensure reliable information exchange on chemical content, and active strategies are required to facilitate that exchange (Rossi 2014).

Forward-looking industries are not only addressing environmental and social sustainability issues related to their production processes and products; they have also begun to identify and address potential risks associated with their upstream supply chains (Foerstl, Reuter and Blome 2010; Boström *et al*. 2015). These sustainability considerations along the supply chain are driven by the objectives of lowering reputational risks, enhancing operational performance, and ultimately enhancing competitiveness. Companies can derive numerous business benefits from sustainable supply chains, including product differentiation; increased market share and growth in consumer support; reduced compliance and supply chain management costs; and better labour productivity (EY 2016).

An important aspect of sustainable supply chain management is companies' understanding of the sustainability priorities of stakeholders, including downstream customers. Understanding these stakeholder concerns may, in turn, be translated into signals to their own suppliers and sub-suppliers (Foerstl *et al.* 2015). Figure 6.1

**Figure 6.1** **Interface of demand and supply in driving the sustainability of chemicals in the supply chain**




Consumers and retailers play important roles in driving demand for safer chemicals and products. At the same time, green and sustainable chemistry innovations can drive the development of safer chemicals and products "downstream" in the value and supply chains. Both "pull" and "push" approaches are important and can complement each other.

represents the interface of demand and supply for sustainable products throughout the supply chain, from consumer retailers and retailer demand to the chemical industry and the suppliers of its feedstocks.

### The role of retailers in influencing upstream supply and procurement

Retailers are in a critical position to drive the sustainability activities of different entities along the supply chain (Sebastiani *et al.* 2015). They are closest to consumers in the supply chain. They also have both financial and reputational incentives to implement management programmes that recognize potential concerns, as well as to reduce or eliminate specific chemicals from products in their supply chain. Consumers in both developed and developing countries consider ingredient transparency to be one of the biggest issues companies face (Retail Industry Leaders Association [RILA] n.d.). Many retailers have become leaders in incorporating sustainability considerations in their business practices and procurement processes (Lo 2013). They are working individually and collectively to discontinue the use of those chemicals of highest concern and thereby address consumer expectations (Box 6.1). This can be done through, for example, chemical ingredient assessment, supplier chemical assessment, restricted substances lists, and substituting or redesigning to eliminate priority chemicals (RILA n.d.).

### The role of downstream product manufacturers and brands

Similarly, proactive product manufacturers engage in voluntary chemicals management practices to stay ahead of compliance regulations and maintain relationships with stakeholders. Many have joined coalitions to collaboratively address sustainable supply chain management, including its chemicals management dimension (Box 6.2). An important component of such chemicals management strategies is enhancing communication about the presence of chemicals in products in the supply chain and assessing potential risk. Increasing preference is being given to suppliers which help companies meet their sustainability goals (EY 2016). Furthermore, certifications and standards that reflect risk-based approaches to sustainability are being advanced, such as the United States Green Building Council (USGBC) initiative on the Integrative Analysis of Building Materials (USGBC 2019).

Companies may also expand their relationships beyond auditing and monitoring, and invest in capacity building and training of suppliers, in order to work towards shared commitments. An example is the amfori Business Environmental Performance (BEPI) Supply Chain Chemical Management module, which supports members in addressing chemical issues in their supply chain within a collaborative framework with common tools and standards. The module

**Box 6.1 Examples of chemical sustainability initiatives in the retail sector**

In 2013 Walmart, one of the world's largest retailers, announced its sustainable chemistry policy. This policy includes goals for restricting 2,700 harmful chemicals in household products by 2022; increased transparency of ingredients; and encouraging suppliers to certify their products to third-party standards such as the US EPA's Safer Choice (Sustainable Brands 2017; Porter 2018; Sager-Rosenthal 2019).

The large North American retailer Target has also announced a new chemical strategy addressing the company's entire value chain and operations and every product it sells. Target has a policy of commitment to transparency, proactive chemicals management, and innovation across all its owned and national brand consumer products and operations (Target 2017; Porter 2018; Sager-Rosenthal 2019). In Europe the home improvement retailer Kingfisher has published a chemicals policy focusing on transparency, chemicals management and innovation (Kingfisher 2018).

The largest pharmacy chain in the United States, CVS, has updated its list of restricted chemicals for use in baby, beauty and personal care and food products. It will remove parabens, phthalates and formaldehyde donors from more than 600 products (Sturcken 2017).

provides a platform and tools to communicate with producers in all tiers, improve their chemicals management and respond to detox concern (amfori 2019).

**Box 6.2** **Downstream sector sustainable supply chain initiatives addressing chemicals of concern**

Responsible Business Alliance
Advancing Sustainability Globally

The Responsible Business Alliance (RBA) is the world's largest industry coalition dedicated to electronics supply chain responsibility. RBA members, which are held accountable to a Common Code of Conduct, use a range of training and assessment tools to support continuous social, ethical and environmental responsibility improvements in their supply chains (RBA 2018).

The Pharmaceutical Supply Chain Initiative (PSCI) was established by the pharmaceutical sector. Its members share a vision of responsible supply chain management, in order to deliver better social, health, safety and environmental outcomes in the communities where they buy. The PSCI created the Pharmaceutical Industry Principles for Responsible Supply Chain Management, which address five areas of responsible business practices and the relevant standards the pharmaceutical supply chain is expected to uphold. It has also developed tools to assess supply chains against the principles, as well as conducting supplier capacity building workshops and events (Mezaros 2017).

The Responsible Beauty Initiative (RBI) was launched by four industry leaders (Clarins, Coty, Groupe Rocher and L'Oréal) and EcoVadis, the leader in supply chain sustainability ratings, as a collaborative effort to strengthen sustainable practices, improve environmental footprints and social impacts, and maximize shared value across their collective supply chain. By using the EcoVadis sustainability ratings tool, RBI members aim to facilitate the social responsibility evaluations of their supplier network and engage suppliers more effectively (EcoVadis 2017). Another example of such an initiative is the Beauty and Personal Care Sustainability Project, which brings together key actors in the value chain (Forum for the Future 2018).

**Box 6.3** **Together for Sustainability: chemical industry collaboration with suppliers to advance sustainability**

Together for Sustainability (TfS) is an industry collaboration of 19 major chemical industry players to drive sustainability in the chemical industry supply chain by adopting a harmonized set of assessment and audit processes, and by developing and implementing a global supplier engagement programme. Through training, events and feedback, TfS raises awareness of sustainability topics among suppliers and supports continuous improvement of suppliers' sustainability performance (EcoVadis 2015).

In 2015 the initiative's members conducted a total of around 5,000 sustainability assessments and audits. The audit results are available to all TfS members with the suppliers' consent. BASF, one of the founding members, audited 135 supplier sites and initiated 1,044 sustainability assessments in 2015. If a need for improvement was discovered, suppliers were supported in the development of measures to meet the required standards. If no improvement took place, the business relationship was terminated. In 2015 four suppliers did not meet requirements (BASF 2015).

### The role of the chemical industry in sustainable supply chain management

The chemical industry has a major role to play in engaging in collaborative relationships, not only with downstream customers through (extended) producer responsibility but also with its own suppliers. Some chemical companies have developed and implemented green and sustainable supply chain management practices with the integration of environmental concerns at the core, such as circular production processes and supply chain management and the tracking of performance and engagement of suppliers through closer supply chain collaborations (Genovese *et al.* 2017). Box 6.3 provides an example of such an initiative.

## 6.2 Information flow on chemicals in the supply chain

### Strengthening two-way communication about chemicals in the supply chain

Producers and brands downstream of the chemical industry have an interest in obtaining information about the chemicals in the products they produce. Practices to strengthen the knowledge base of a producer include obtaining information on the chemicals present in articles; data on releases during production and from products; and safety information (e.g. from safety data sheets) to be provided to worker safety managers, retailers, consumers and other stakeholders. In addition, traceable information on waste handling and associated recycling processes can prevent the unintended contamination of products made from recycled materials. For example, the Proactive Alliance (a group of industry representatives seeking full material disclosure of chemicals, including retailers and product manufacturers) is exploring the possibility of a global cross-sectoral standard for exchanging data on individual articles. Its aim is for this standard to enable transferring data on substances in articles from one sector to another and to foster simpler compliance declarations. This initiative addresses the challenge that many sectors have material declaration systems, while no standard exists for sharing information between companies in different sectors (Stringer 2018).

Taking a product life cycle perspective helps producers to better understand the supply chain from a sustainability point of view, and to evaluate a holistic approach to address environmental, economic and social impacts. However, effective communication between actors in the supply chain is challenging and may be complex. Both push and pull concepts are relevant to improving flows of relevant data and information in the supply chain. The push dimension refers to chemical industries' responsibility to follow the use of a chemical through the chain leading to its customers, while the pull dimension refers to retailers, product manufacturers and brands pulling information from their upstream suppliers, including from the chemical industry.

### Use of information tools to increase transparency on chemicals in the supply chain

There is an increasing range of available tools companies can use to communicate sustainability information along the supply chain. For example, companies may ask suppliers to fill in forms about the chemical content of products (Scruggs 2013). Eco-labelling and social labelling can be used to verify compliance with important aspects of sustainability and to hold suppliers responsible for ensuring sustainability in supply chains. The *Blauer Engel* (Blue Angel), the German government's eco-label, has established standards for environmentally friendly products and services which are decided by an independent jury according to defined environmental and sustainability criteria. Around 12,000 products and services from some 1,500 companies have been awarded the Blue Angel. Another example is the Safer Choice programme (formerly Design for Environment, DfE), administered by the US EPA, whose label covers over 2,000 products and includes requirements for performance, packaging, pH and VOCs (Perlmutter 2015).

At the global level, under SAICM the Chemicals in Product Programme led by UN Environment (see Part II, Ch. 4) brings together SAICM stakeholders to strengthen information flow on the presence of chemicals throughout the supply chain. An assessment of different tools for, and approaches to, managing material information in global supply chains prepared within this framework by UNEP's Chemicals in Products project found that IT-supported information exchange systems providing "full material disclosure" (FMD) were the most advanced solution (UNEP 2015).

Supplier codes of conduct are a way to establish sustainability expectations for the supply chain, which supply management professionals, suppliers and other actors can use to make informed decisions (UNEP 2014). Supply chain information systems and product information systems provide information on restricted chemicals and material declarations. For example, use of the Globally Harmonized System for Classification and Labelling (GHS) promotes the transfer of information to users of chemicals through labelling and safety data sheets (Swedish Chemicals Agency 2016). Other tools include auditing procedures, procurement guidelines and eco-branding (Boström *et al.* 2015).

While the chemical industry needs to implement effective communication and information exchange with its suppliers, it also needs to engage with downstream partners to ensure

**Box 6.4 Strengthening information flows between the chemical industry to downstream customers**

The International Council of Chemical Associations (ICCA) represents chemical manufacturers and producers around the world. ICCA members account for more than 90 per cent of global chemical sales. Increasingly, consumers seek more detailed information from product manufacturers about ingredients in the products they use. The ICCA launched a Value Chain Outreach programme, starting with the electronics sector and later extending it to the automotive and textiles sectors. Through this programme chemical companies aim to improve communication with retailers, product manufacturers and others along the chemical value chain concerning how to safely manage and use chemicals throughout their entire life cycle, from production, transport and use through eventual recycling or disposal. Each part of the value chain shares responsibility (i.e. through product stewardship) for prioritizing health, safety and environmental protection at each stage of the chemicals' life cycle (ICCA 2015; Patel 2016).

that chemical safety information is appropriately communicated and that chemicals are put to their intended use. Box 6.4 provides an example of a chemical industry initiative to strengthen communication with downstream product manufacturers.

The supply chain, and the ability to trace chemicals, become increasingly complex along the value chain. Participants in the value chain maintain records and update them continuously, which must also be carried out by others in the network. As a result, participants in the supply chain potentially incur costs and delays and must address inaccuracies, which could be further complicated due to third party audits. Important information about chemicals in products may be missed out using this approach.

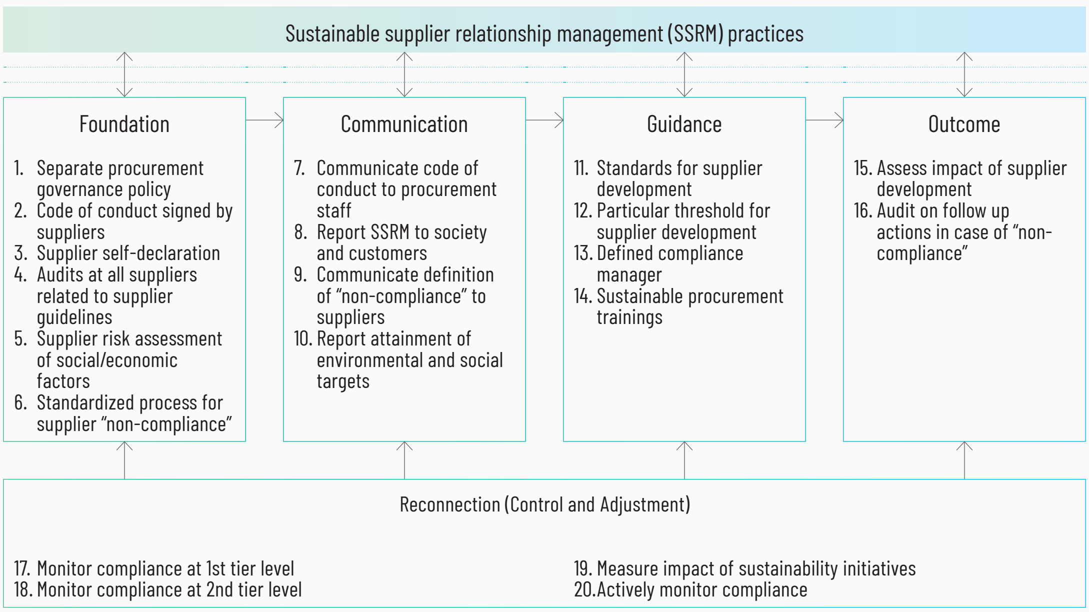
While existing IT solutions such as the International Material Data System (IMDS) or the Sustainability Data Exchange Hub (SustainHUB) are effective, the use of blockchains (lists of cryptographic information about individual business-to-business supply chain transactions) can help decentralize and optimize necessary information flows and bring greater efficiencies to global chemical supply chains (Goodnight 2017). Blockchains could create a new model of trust by establishing transactional relationships between businesses through smart contracts, certifications and compliance (International Business Machines Corporation 2018).

## 6.3 Collaborative relationships for sustainable supply chain management

### Sustainable Supplier Relationship Management

Successfully managing the cross-border and often sector-spanning nature of complex supply chains entails governance challenges. These include addressing geographical distances in the supply chain; information, communication and knowledge exchange related to supply chain complexity and fragmentation; compliance and implementation gaps; challenges in supply chain power relations; and credibility issues (Boström *et al*. 2015; Blome, Foerstl and Schleper 2017).

**Figure 6.2** **Sustainable Supplier Relationship Management (SSRM) practices (adapted from Leppelt *et al.* 2013, p. 100)**



Stakeholders often hold the buying companies responsible for compliance issues in their upstream supply chains. To address sustainability concerns in upstream supply chains, companies need to implement measures that substantially affect supplier conduct, with many firms relying on improving sustainability performance in the supply base through proactive supplier management (Marquis, Toffel and Zhou 2016). There is an overview of measures to manage supply chains and relationships with suppliers, in order to meet sustainability objectives, Figure 6.2 An important aspect of this framework is the fostering of behavioural change in suppliers in a cooperative manner, through "inclusive multi-stakeholder coalitions" rather than through prescriptions by the customer.

### Broader governance measures need to support tools

While the tools discussed above are important, in most cases they are not sufficient in themselves to overcome the geographical, informational, communication, compliance, power and legitimacy challenges that are barriers to sustainable global supply chains. Therefore, it is suggested that such tools be used with a wider range of approaches including (Boström *et al.* 2015):

- coalition and institution building on a broader scale (e.g. through developing inclusive multi-stakeholder coalitions);
- ensuring flexibility to adapt global governance arrangements to local social and environmental contexts of production and consumption;
- supplementing effective monitoring and enforcement mechanisms with education and other programmes to build compliance capacity; and
- integrating reflexive learning to improve governance arrangements over time.

## 6.4 Considering circularity in supply chain management

Resource efficiency considerations include transitioning from a traditional linear flow of materials in a "take-make-use-dispose" economy

**Box 6.5** **The Circular Economy Package (EC 2018)**

The Circular Economy Package was adopted in December 2015 by the European Commission. Four objectives were formulated that pinpoint the direction of innovation in circular supply chain management and are relevant to chemicals and waste management (EC 2018):

- Ensure that appropriate information on substances of concern in products is available to all actors in the supply chain and ultimately also becomes available to waste operators. This will contribute to the promotion of non-toxic material cycles, and improve the risk management of chemicals during repair and other forms of reuse and in waste recovery processes.
- Make recycling easier and improve the uptake of secondary raw materials by promoting non-toxic material cycles. In addition, when considering possible chemical restrictions and exemptions to restrictions, more attention needs to be given to their impact on future recycling and reuse.
- Enable a more harmonized interpretation and implementation of end-of-waste rules across the EU to further facilitate the use of recovered material within the EU.
- Ensure a more consistent approach between chemicals and waste classification rules.

In the corresponding EU Action Plan for the Circular Economy, it is stressed that the functioning of value chains needs to be rethought. Value chains, especially for complex composite materials (e.g. plastics) or chemical formulations (e.g. plant protection products), are closely connected with the creation of material cycles, where hazardous chemicals are reduced to a minimum in support of a "non-toxic environment" (Goldenman *et al.* 2017). The new database to be hosted by the European Chemicals Agency (ECHA), created under the amended Waste Framework Directive on the presence of substances of very high concern (SVHC) in articles, is a concrete measure to help achieve this goal (ECHA 2018).

to a more circular flow of materials. In this approach a core principle is the elimination of waste through improved design of products, use of processes that have increased resource efficiency, and increased recyclability of materials (Sheldon 2016). Circular supply chains therefore cover remanufacturing, reuse and recycling processes (Dora, Bhatia and Gallear 2016; Genovese *et al*. 2017). Maintaining the value of materials, products and resources in the economy for as long as possible, and minimizing waste generation, represent an essential contribution to the development of sustainable, low-carbon, resource-efficient and competitive economies (EC 2015). Box 6.5 describes the Circular Economy Package adopted by the European Commission.

End-of-life treatment of chemicals and products is the stage at which improved waste management and recycling strategies are considered. In a circular economy, materials that can be recycled are inserted back into material and product life cycles as "secondary raw materials". One barrier to promoting the use of secondary raw materials is uncertainty about their performance quality and chemical content, including possible contamination. Chemical contamination of articles may prevent recycling, or it may present new, unexpected exposure situations if contaminated recycled materials are used in products when use of these substances was not foreseen (Goldenman *et al.* 2017). In the fashion industry some retailers allow customers to exchange unwanted clothes for a discount, so as to use them as raw material for new products. Due to complex supply chains, companies often do not have an adequate understanding of conditions in far-away factories, including chemical use (Bomgardner 2016). Promotion of uncontaminated material cycles and better tracking of chemicals of concern in products can help address these concerns and facilitate recycling through the uptake of secondary, non-toxic raw materials. Improved tracking of chemicals of concern should also be used to identify contaminated materials in the waste stream and separate them, in order to maintain a high recycling rate while generating uncontaminated secondary raw materials.

Many stakeholders have embraced the circular economy approach. The ICCA, for example, has expressed its commitment to play a key role in the systemic transition to a circular economy as a key component of sustainability, whereby resources and materials are continuously cycled to eliminate waste while creating value for all. According to this view, circular economy initiatives must embrace a holistic view of the economy that considers both environmental and societal impacts of a product or material across its life cycle. Enabling policies are needed that take a holistic view and consider all stages of a product life, including the closure of loops at end-of-life, while being transparent, risk-based and flexible in nature. This will unleash market forces that drive innovations towards a circular economy.

## 6.5 Integrating life cycle thinking and sustainability into product design

### Taking a systems approach in designing products

To address challenges associated with chemicals and their products, it may not be sufficient to base chemical synthesis on functionality criteria only (e.g. water repellency, resistance to high temperatures and economic viability). Sustainable design and supply chain solutions go a step further, considering life cycle impacts, from synthesis (energy, water, other chemical use) to toxicity and environmental effects, during the product life cycle as components of chemical and product design criteria. Chemical and product design, synthesis and manufacturing are therefore important stages for the implementation of broader sustainable supply management strategies, which can be understood as a systemic shift involving both technological and non-technological innovations (Kirchherr, Reike and Hekkert 2017; Homrich *et al.* 2018).

The coordination of product and supply chain design decisions plays a critical role in improving the sustainable supply chain's performance. A product's design determines its future costs, which in turn depend on the supply chain configuration (e.g. the number and locations of supply chain partners, and their capabilities and capacities) (Metta and Badurdeen 2013). Integrating product design in the supply chain is therefore a basis for establishing sustainable competitiveness in increasingly complex customer markets. Moreover, integrating product design in the supply chain increases communication, supply chain visibility and responsiveness, as well as reducing supply chain risk (Khan *et al.* 2016). Box 6.6 describes the Design Thinking approach to advance sustainability.

### Green and sustainable chemistry design considerations along the supply chain

Green and sustainable chemistry, as already discussed, encompass the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes (Friege 2017). While the focus of green chemistry is on reducing waste, increasing yield and reducing non-renewable energy and material input (along with environmentally conscious

**Box 6.6 The Design Thinking approach to advance sustainability**

Design Thinking is a systematic approach to solving complex problems associated with all aspects of life. In contrast to conventional approaches, starting with technical solvability, Design Thinking puts customer needs (as well as user-centred inventions) at the heart of the process. It also requires steady back-coupling between the innovator and the customer. However, Design Thinking is not only about product and service innovation. It is a means of increasing the problem-solving competence of the user, or of the companies using it, for all kinds of product and service innovation. Design Thinking is also increasingly used in revising internal company processes, especially in areas such as finance and accounting, the supply chain, personnel administration and client management, complementing what traditional methods (e.g. Lean Six Sigma) have to offer (Waerder, Stinnes and Erdenberger 2017).

**Table 6.1 From traditional to green and biomimetic chemistry technologies (Van Hamelen 2018, p. 6)**

| TRADITIONAL | GREEN AND BIOMIMETIC |
|---|---|
| › "Heat, beat, treat": chemical reactions under high temperature, high pressure and chemical treatment<br>› Organic solvents<br>› Fossil feedstock and fossil energy<br>› High purity of feedstock is imperative<br>› Use of the entire periodic system<br>› Resources sourced globally<br>› Controlling risk by taking safety precautions | › Chemical reactions take place at room temperature and pressure<br>› Water as solvent<br>› Low-energy chemical reactions<br>› Local feedstocks, diverse sources<br>› Degradation is part of design: "timed degradation" of "triggered instability" (John Warner), "Nature's disassembly processes" (Janine Benyus)<br>› Functionality is created by the structure, not the material itself<br>› Living systems only utilize 25 elements; carbon, oxygen and sodium make up 96 per cent of atoms in living systems; other elements are used in trace amounts<br>› Controlling risk by adopting the inherent properties of the materials |

design of chemical reactions and products), sustainable chemistry has a broader focus, in line with broader sustainable supply chain approaches. Table 6.1 provides an overview of approaches that can help move from traditional to green and biomimetic technologies that enable the transition to circular and sustainable supply chains.

## 6.6 Measures to strengthen sustainable supply chain management

Sustainable supply chain management plays a key role in ensuring that purchasing and procurement decisions comply with sustainability criteria, and that they create a force that will drive upstream suppliers to participate in the growing markets for sustainable products. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to strengthen sustainable supply chain management:

- Develop sustainable chemistry supply chain policies throughout the supply chain.
- Enhance information sharing among all actors in the supply chain, on chemicals in products and chemicals in products' waste, and harmonize approaches to share such information.
- Develop collaborative approaches to sustainable supply chain management in the private sector that bring together companies in specific sectors, and include other stakeholders.
- Promote emerging good practices and initiatives in sustainable supply chain management for chemicals and waste in countries where these ideas, practices and initiatives are less well-known.
- Take proactive corporate measures to design sustainable products and sustainable solutions, and become market leaders, taking into account green and sustainable chemistry approaches.
- Strengthen legislation on the chemicals and waste interface, in order to provide clear guidance to recyclers that will advance non-toxic materials flow.

# 7/ Sustainability metrics and reporting: measuring progress, strengthening accountability

## Chapter Highlights

A variety of metrics exist to assess the chemicals and waste dimension of companies and producers, including life cycle assessment and chemical footprint indicators.

Reporting by industry is increasing, and self-reporting in the chemical and related industries is complemented by independent external assessments.

Opportunities exist to link, align and/or develop metrics and reporting standards, drawing on existing international initiatives.

Stakeholders can take further steps to increase both transparency and rigour, thereby ensuring that metrics are fit for purpose and audience.

Opportunities exist to develop a common understanding of green/sustainable chemistry metrics.

Metrics and industry sustainability reporting could become important aspects of measuring progress in a beyond 2020 framework.

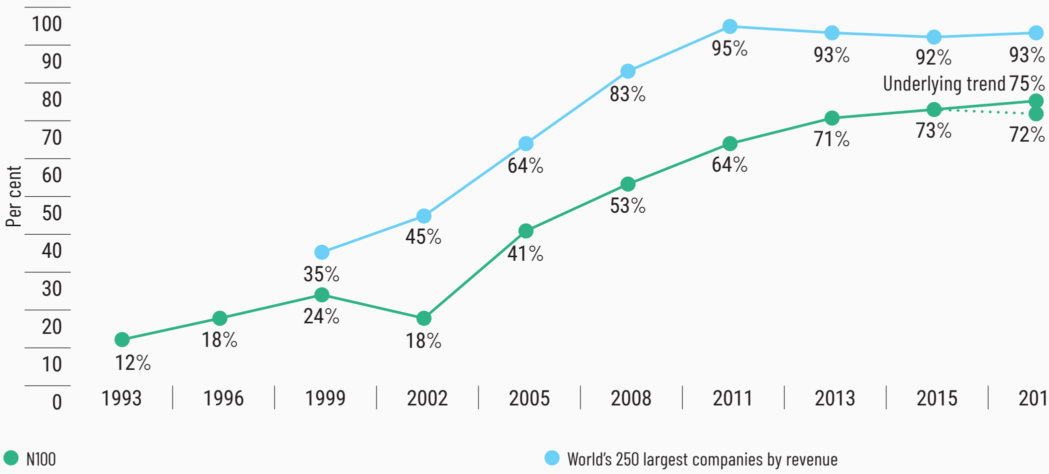
Private sector initiatives and standards, including on chemicals and waste, have been mentioned in various chapters of the GCO-II. This chapter discusses metrics and reporting schemes aimed at providing interested stakeholders with knowledge about the performance of the private sector related to sound management of chemicals and waste. The chapter is not able to cover all relevant initiatives. Nor does it seek to judge the merit of the schemes mentioned. Rather, by drawing attention to the topic, it aims to raise the question of how metrics and reporting schemes could fit into, and be strengthened within, a global approach on chemicals and waste beyond 2020.

## 7.1 The growing momentum of private sector sustainability metrics and reporting

### An increasing number of companies report on their sustainability performance, including that related to chemicals and waste management

Traditional corporate reporting has focused on information that may influence the decisions of those who consult a company's financial statements, such as investors. More recently, momentum has been generated to integrate sustainability aspects into corporate reporting. According to some estimates, the share of the world's 250 largest companies reporting on their sustainability performance increased from 35 per cent in 1999 to 93 per cent in

**Figure 7.1** Share of the top 100 companies in 34 countries (N100) and of the world's 250 largest companies providing corporate responsibility reports (per cent), 1993-2017 (adapted from Blasco *et al.* 2017, p. 9)




The survey's findings indicate that corporate responsibility reporting has become standard practice for most large and medium-sized companies across the world. The terms corporate responsibility, corporate social responsibility, and environmental, social and governance are often used interchangeably.

2017 (Blasco *et al.* 2017). The use of metrics to assess companies' environmental, social and governance (ESG) performance, as well as their economic performance, has grown significantly, particularly in the Asia-Pacific region (KPMG *et al.* 2016). While the majority of countries in the world have sustainability reporting policies, such policies are still largely lacking in Africa and West Asia (Global Reporting Initiative [GRI] 2016).

Sustainability reporting is often based on formalized standards and guidance, and the use of the majority of sustainability reporting instruments is mandatory (KPMG *et al.* 2016). However, a growing share of reporting (approximately one-third in 2016) is voluntary (KPMG *et al.* 2016). Materiality in sustainability reporting implies a broader scope, including aspects that may affect the company's "ability to create, preserve or erode economic, environmental and social value for itself, its stakeholders, the environment, and society at large" (GRI n.d.). If actors focus on short-term financial aspects, disclosure may lead to management and investment decisions that are suboptimal from a sustainable development perspective.

### Regulations, consumers, and actors in the supply chain drive sustainability reporting

While regulation – and the need for compliance – continue to be major drivers of sustainability reporting (Cockcroft and Persich 2017), there is growing awareness in the corporate sector that strong performance on sustainability issues and transparent reporting are beneficial to business and provide new opportunities to generate revenue. In the long term, companies which voluntarily adopt sustainability policies have been shown to significantly outperform their counterparts in terms of market and accounting performance (Eccles, Ioannou and Serafeim 2014). Companies thus have an intrinsic interest in making their contributions to achieving the SDGs more visible and communicating them, given that these contributions may be overlooked or not adequately attributed. Sustainability reporting may also change perceptions of the chemical industry and increase competitiveness, thereby attracting new talent (WEF 2019).

The general public and consumers are a main driver for these developments. They are increasingly conscious of (and demand information about) the sustainability performance of companies and/or products before making choices. The need to gain the trust of society is thus an important driver for transparency (WBCSD 2014). NGOs seek to provide relevant information and place pressure on companies, naming frontrunners and shaming laggards (Follette *et al.* 2017). Retailers may be particularly sensitive to this driver, consequently exerting pressure on suppliers. Suppliers, in turn, are likely to signal a need for information on sustainability performance further upstream. Equally important, the chemical industry, further upstream, is assessing, auditing and communicating its performance, including that of suppliers, as is done through the Together for Sustainability (TfS) initiative (TfS 2016). Sustainability reporting by various actors along the supply chain thus becomes an important source of information for corporate decision-making.

Financial market actors also use sustainability performance and non-financial information in making investment decisions (Deloitte 2016). This steers companies towards improved sustainability policies and long-term value creation, as exemplified by a recent letter to CEOs from Blackrock, the world's largest asset manager (Fink 2018).

## 7.2 A snapshot of private sector metrics and reporting on chemicals and waste

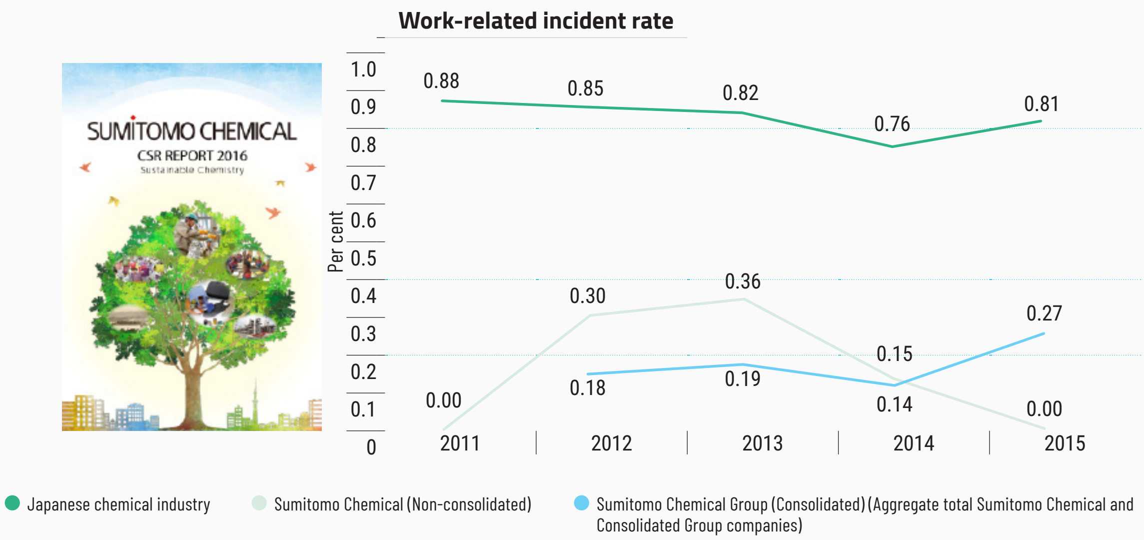
### 7.2.1 Metrics and reporting developed by industry

#### The chemical industry

RESPONSIBLE CARE®
OUR COMMITMENT TO SUSTAINABILITY

Industry associations also play a role in communicating sustainability performance. In the context of the Responsible Care® initiative of the International Council of Chemical Associations (ICCA), participating companies collect and report data for a set of environmental, health and safety performance measures. While the number of organizations reporting under Responsible Care® has varied over the years, reporting rates have increased overall. For example, the number of organizations reporting on fatalities in the workforce increased from 25 in 2000 to 42 in 2013 (ICCA 2015). In the United States, a Responsible Care® Management System has been established that includes independent third-party certification and transparent reporting and performance metrics (ICCA 2015). This management system has the potential to serve as the benchmark for

**Figure 7.2** Snapshot of Sumitomo's Corporate Social Responsibility Report: work-related incident rate (per cent), 2011-2015 (adapted from Sumitomo Chemical Group 2016, p. 10)



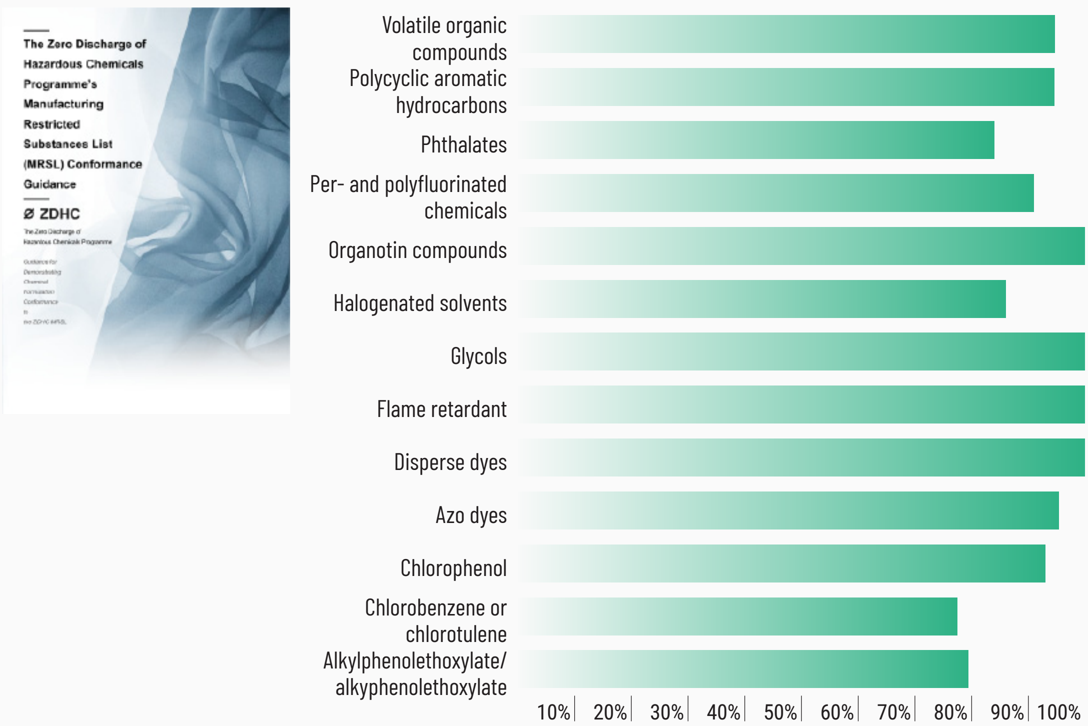
monitoring and assessing implementation in other countries.

Almost all major chemical companies now publish regular reports on ESG performance. For example, the Dow Chemical Company (2017) and the Sumitomo Chemical Group (2016) publish sustainability reports on a regular basis to communicate performance on selected indicators, increasingly mapped against the SDGs. Under Chemie3, a sustainability initiative of the German chemical industry tailored in particular to SMEs, 40 economic, environmental and social indicators have been developed to measure progress towards sustainable development, such as product safety and resource efficiency. Progress against the indicators is reported publicly and on a regular basis (Chemie3 2018). In some cases approaches are developed in collaboration with external partners, as in the case of the Additives Sustainability Footprint of the PVC industry (UN 2018).

## Downstream sectors


Efforts to self-assess and report sustainability performance across the supply chain can also be observed among chemical-intensive downstream companies and retailers. One example is the

**Figure 7.3** ZDHC and PUMA's rates of compliance with MRSL parameters in wastewater (per cent), 2017 (adapted from PUMA 2018, p. 10)



**Box 7.1 Johnson's Greenlist™ Programme (GC3 n.d. a)**

S.C. Johnson is a formulator of chemical-intensive products used in millions of households. In 2001 the company, which does not produce the ingredients that go into its products, launched an innovative chemical classification process called Greenlist™ that rates raw materials based on their impact on human health and the environment. The scores are reported alongside performance and cost information in the company's chemical formulary, so that chemists can easily compare these materials. Over time most suppliers have embraced the Greenlist™ protocol. The programme has evolved to the point that suppliers are designing new chemicals based on the Greenlist™ scores.

Zero Discharge of Hazardous Chemicals (ZDHC) initiative, which covers the global textile, leather and footwear sectors (ZDHC 2018). This programme brings together 24 signatory brands, 53 value chain affiliates and 15 associates whose aim is to eliminate the use of priority hazardous chemicals throughout their value chains. The ZDHC Roadmap to Zero Programme includes harmonized approaches in areas such as its manufacturing restricted substances list (MRSL), wastewater quality, audit protocols, and data and disclosure (Figure 7.3). Rates of compliance are made publicly available (ZDHC 2018).

### 7.2.2 Independent assessment schemes with industry participation

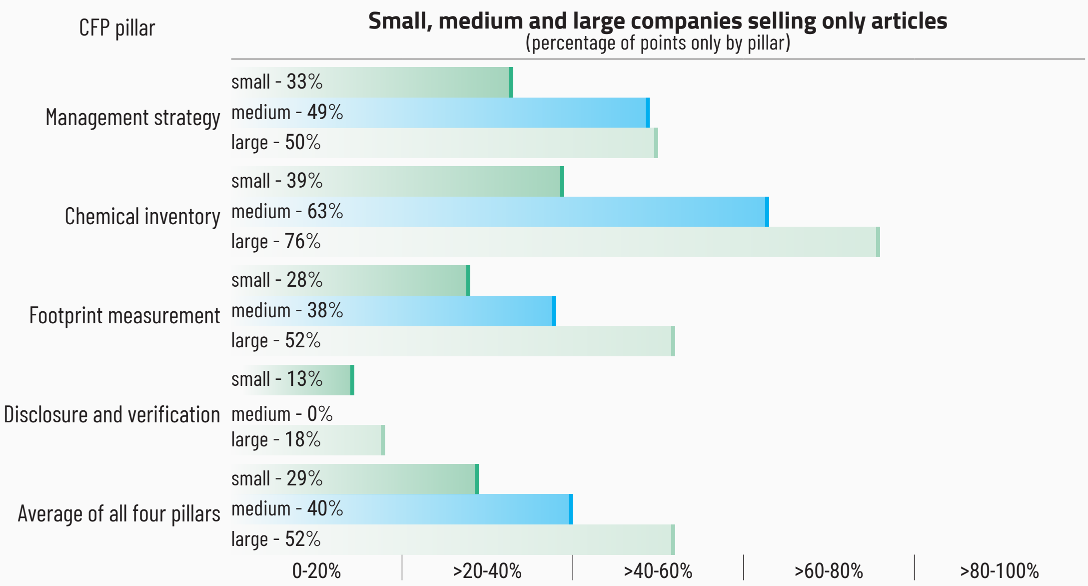
Companies may choose to engage with external bodies to assess and certify their products based on a set of criteria covering selected economic, social and/or environmental topics. This may include product recyclability assessment and certification schemes, such as the Cradle to Cradle Product Standard (Cradle to Cradle Products Innovation Institute 2018) and the textile production and product-specific Bluesign (Bluesign 2018). Environmental Product Declarations are another reporting tool which companies all along the supply chain can use to disclose environmental impacts throughout the life cycle of products, including aspects related to waste management and disposal (International EPD System 2017). In the building sector, the membership-based United States Green Building Council (USGCG) provides third-party certifications of buildings meeting certain sustainability criteria (USGBC 2018).

The Future-Fit Business Benchmark (Future-Fit Foundation 2017) seeks to support both chemical companies and downstream actors in articulating, assessing and transforming how they create long-term value for themselves and society as a whole. This approach is based on the identification of an extra-financial break-even point for business, expressed as a unified set of social and environmental goals drawing, among others, on criteria such as chemical releases and the use of chemicals that are likely to build up in nature and/or are considered harmful according to the SIN (Substitute It Now!) List (International Chemical Secretariat [ChemSec] 2017). Under the Future-Fit scheme, independent assurance by third parties and publication of the scores is optional.

Some of these schemes focus on assessing and communicating performance to downstream users and the general public. The Chemical Footprint Project (CFP), for example, provides a quantitative metric which manufacturers, brands and retailers can use to measure progress in reducing the use of chemicals of high concern. Participation is voluntary and the results are made publicly available (Rossi *et al*. 2017).

A number of broader sustainability reporting initiatives are in place that also cover – to a varying extent – topics relevant for the sound management of chemicals and waste. The Global Reporting Initiative provides widely used Sustainability Reporting Standards which include guidelines and standards that companies and

**Figure 7.4** **Average percentage of points across four Chemical Footprint Project (CFP) pillars scored by small, medium and large companies selling only articles (adapted from Rossi *et al.* 2017, p. 7)**




other organizations can use for sustainability reporting (GRI n.d.). The Sustainability Accounting Standards Board (SASB) provides standards for integrating relevant ESG considerations into reporting. They cover 79 industries in 11 sectors. Likely material sustainability issues for disclosure by the chemical industry identified include, among others, wastewater management; waste and hazardous materials management; employee health and safety; life cycle impacts of products and services; and accident and safety management (SASB 2015; SASB 2018).

### 7.2.3 Independent external assessment of industry performance

Growing investor interest in corporate sustainability performance has led to the incorporation of more detailed information on chemicals and waste management in external assessment schemes. Under the Dow Jones Sustainability Index, for example, chemical suppliers and downstream companies are requested to provide information on the percentage of products that contain substances regulated as hazardous, are of international concern, or may become regulated in the future, as referenced by ChemSec's SIN List (ChemSec 2017). Various service providers assess performance on environmental, social and governance topics, including chemicals and waste management, to allow investors to assess respective risk profiles (Sustainalytics n.d.).


A number of initiatives provide independent assessments of chemicals and waste management performance directed to consumers and the general public. For example, the Mind the Store initiative in the United States informs consumers by providing an aggregate grade based on criteria such as whether a policy is in place to ensure that suppliers conduct credible hazard assessments for alternatives to chemicals of high concern

**Box 7.2 Sustainability information of relevance to the financial sector**

The financial sector is important in driving the demand for information on sustainability performance of companies. A number of metrics and reporting schemes exist to inform investment decisions, including the following:

- *ESG (environmental, social and governance) factors*: These are a subset of non-financial performance indicators which include sustainable, ethical and corporate governance issues and ensuring there are systems in place to ensure accountability. The UN-backed Principles for Responsible Investment (n.d.) provide a voluntary ESG framework for companies and funds, on the basis of which investors can make informed investment decisions with respect to sustainability and governance practices (UNEP and World Bank 2017; Financial Times n.d.).
- *Environment-related financial disclosure and transparency*: This allows investors to exclude companies in the chemical industry or among downstream users of chemicals, including formulators and retailers, which are not working towards the implementation of more sustainable practices.
- *Environmental disclosure on stock exchanges*: Stock exchanges have historically played an important role in economic growth and development through enabling effective capital allocation. It is increasingly clear that environmental and social issues have an impact on corporate performance. Therefore, stock exchanges (or the relevant securities regulators) should require disclosure in the same way that financial disclosure is required (Cleary 2015).
- *Environmental and sustainability stock market indices, ratings and associated products*: These are useful to investors as they seek to shift to more sustainable investment (Cleary 2015). It is important that robust methodology be used, which can address relevant green and sustainable criteria within the chemical industry and downstream use sectors.
- *Environmental risk management by financial institutions*: This includes risk management frameworks, such as the Equator Principles, which are adopted by financial institutions to determine, assess and manage environmental and social risk in projects. It is primarily intended to provide a minimum standard for due diligence and monitoring to support responsible risk decision-making. The most recent version of the Equator Principles (currently under review) advises that assessment documentation may include "pollution prevention and waste minimization, pollution controls (liquid effluents and air emissions), and solid and chemical waste management" (Equator Principles 2013).

(Safer Chemicals, Healthy Families 2018a). Others provide consumers with online product and ingredient information to help guide better informed buying decisions for specific applications (GoodGuide 2018). The scientific community also provides information on the sustainability performance of relevant stakeholders, including the chemical industry. For example, one study (Britzelmaier *et al.* 2015) assessed the corporate sustainability management of international chemical companies across four categories: reporting, ecology, environment and economy.

Eco-labelling can be a useful tool to encourage more sustainable production and consumption by helping customers from the public and private sectors identify greener and more sustainable products. Eco-labelling uses specific criteria (e.g. hazard properties) to provide information about the environmental characteristics of a product. Such labels are initiated in some cases by governments and in others by the private sector. In recognizing that environmental concerns may become a market advantage, private companies use eco-labels to increase awareness and influence consumer decisions through their purchasing (Tranchard 2018; International Organization for Standardization 2019). An example of a certification scheme for products and services that also covers chemicals and waste related issues is the *Blauer Engel* (Blue Angel) in Germany.

## 7.3 Green and sustainable chemistry within metrics and reporting schemes

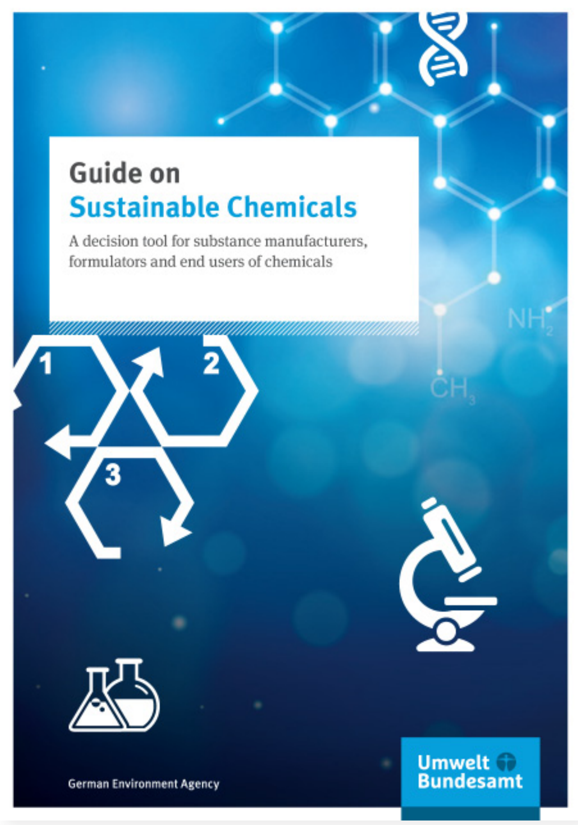
### Stakeholders use the green and sustainable chemistry concepts in standards and reporting

In their reporting, various stakeholders use the terms "green chemistry", "green engineering" and "sustainable chemistry". In doing so, some have developed their own metrics to measure performance. For example, Dow has set a goal of increasing sales of sustainable chemistry products, defined sustainable chemistry, and developed a Sustainable Chemistry Index to track progress. The index combines variables such as the recycled content of the product, its social benefit, and risks it may pose at the end of the life cycle (Dow Chemical Company 2015). Sigma-Aldrich has developed a quantitative assessment of a product's performance against the 12 Principles of Green Chemistry in order to optimize the manufacturing process accordingly (Sigma-Aldrich n.d.). S.C. Johnson applies requirements for full disclosure of products' ingredients and green chemicals selection criteria (S.C. Johnson & Son 2018).

### Exploring the potential of sustainable chemistry metrics to assess and communicate performance

As highlighted in Part I, Ch. 1, there is currently no common understanding among stakeholders of sustainable chemistry or how to assess information about the sustainability of chemical processes and products. A recent report by the United States Government Accountability Office (2018) highlights the challenges of using different metrics, which incorporate different factors, in order to evaluate the sustainability of processes or products. It finds that this impedes the development and adoption of sustainable chemistry technologies, while there is as yet no common understanding of how to measure progress towards green and sustainable chemistry.

Efforts are under way to advance a common understanding of green and sustainable chemistry. For example, one study (Tickner and Becker 2016) explores how measuring progress towards mainstreaming green chemistry requires the use of relevant metrics at the molecular/process level (e.g. water usage in the process), the product and material level (e.g. the inherent hazard of chemicals or materials in a product), the firm and sector level (e.g. the existence of effective chemicals management strategies), and the societal level (e.g. the production volume of chemicals meeting the Principles of Green Chemistry) in a complementary manner (see also GC3 n.d. b).




The German Environment Agency (UBA) developed a *Guide on Sustainable Chemicals*, a decision tool for substance manufacturers, formulators and end users (UBA 2011). Since 2016 there is a corresponding IT tool, SubSelect (UBA 2016), which can be used to measure the sustainability of Chemical Leasing projects (UBA 2018) and has an ongoing activity on sustainable chemistry case studies. At the international level, UNEP has developed an analysis of submissions of cases from stakeholders that have relevant experience with the issue of sustainable chemistry, in response to a mandate received from the second UN Environment Assembly (UNEA-2). Among other considerations, it looks at the possibility of developing practical guidance on sustainable chemistry (UNEP 2019).

## 7.4 Strengthening the chemicals and waste dimension of sustainability metrics and reporting

### The metrics and reporting landscape is complex and fragmented

The rapid proliferation of sustainability reporting instruments has created a complex and fragmented landscape (KPMG *et al.* 2016). One study found more than 2,500 different metrics for supply chain performance reporting (Ahi and Searcy 2015). While the availability of a large set of metrics may allow companies to report on specific aspects of particular relevance, it also presents challenges in regard to providing meaningful information. Technological advances (e.g. in the context of big data) could help in gathering and analyzing publicly available sustainability reporting data, in order to create useful data points for chemicals management across the value chain.

Sustainability instruments and metrics to assess performance with respect to chemicals and waste vary significantly, for example in terms of who undertakes them, who/what is being evaluated, the scope of the assessment, and the methods used and the audience. Depending on these variables, the results communicated in terms of chemicals management performance, along with the transparency of the scheme, may vary significantly. To ensure credibility, and to avoid the suspicion of "greenwashing", it is important for methods to be transparently documented (Berrone 2016; Stacchezzini, Melloni and Lai 2016). It has been argued that the growing number of footprint indicators, and the absence of consistent methods, may result in incoherence and contradictory results which could also hamper the usefulness of such reporting for policymaking and corporate decision-making and represent a market barrier for green products (Ridoutt *et al*. 2015).

### Integrating chemicals and waste into metrics and reporting schemes

A review of existing sustainability metrics and reporting in the chemical industry focuses on "traditional" environmental and social concerns such as job creation, labour rights, carbon footprints and resource efficiency. Specific issues of relevance to chemicals management are often inadequately addressed and not integrated into companies' sustainability strategies (Cockcroft and Persich 2017). Similarly, related and chemical-intensive downstream industries could enhance the consideration of chemicals and waste in their reporting efforts. Opportunities also exist to further and more comprehensively integrate chemicals and waste management issues into existing and widely used reporting schemes like the GRI.

### Ensuring that metrics are fit for purpose and audience

In some cases simplified metrics are needed for effective communication of relevant information to the target audience, such as investors or consumers. Footprint indicators aim to do this by providing a single consolidated metric. However, depending on the approach used, footprints could also be used to draw attention to a selected stage of the life cycle while neglecting others, which might give an incomplete picture of the environmental impact. Life cycle assessments may help provide a more comprehensive picture, including of potential trade-offs across different stages of the life cycle, thus providing a more useful basis for decision-making in certain contexts. Meanwhile, increased complexity comes at a cost and the results may be less easily accessible to non-experts (Ridoutt *et al*. 2015).

Existing sustainability metrics and reporting schemes have been criticized for not placing the reported indicators in the environmental, social and economic context as this applies at the relevant level (local, regional, global) (McElroy and Baue 2013; Kropp 2014; Haffar and Searcy 2018). Context-based metrics that give due consideration to relevant thresholds, including where these are not fully understood, may help determine the value of companies' reported

efforts to increase the sustainability performance of their portfolio. As regards chemicals and waste, this could prove a straightforward exercise in some areas but a more complicated one in others, as is also evident from the difficulties of identifying a measurable planetary boundary for chemical pollution (Robèrt, Broman and Basile 2013; Diamond *et al.* 2015). More research may be needed in order to explore the value and feasibility of context-based sustainability metrics.

### Taking steps towards coherent metrics and reporting

There may be value in exploring opportunities to align and/or develop harmonized metrics and reporting standards, as appropriate (e.g. at the sectoral level). Such efforts could draw on existing international standards in order to increase efficiency and the comparability of results. Life cycle approaches, for example, could draw on International Organization for Standardizaton (ISO) standards 14040 and 14044, which specify requirements and provide guidelines for life cycle assessment (Ridoutt *et al.* 2015).

Some progress has been made towards the establishment of binding global norms in the area of sustainability reporting. At the UN Conference on Sustainable Development in Johannesburg (UN 2012), several proposals were discussed concerning a potential legally binding instrument on sustainability reporting for certain corporations. This concept was based on the "report or explain" approach that has become law in Denmark and is a requirement for companies listed on some stock exchanges. Although the initiative failed, it had the support of various private businesses, including strategic investors and insurers, and the debate around the various proposals has perhaps opened the door to broader consideration of mandatory environmental and social performance standards (Stec, Paszkiewicz and Antypas 2017).

Proposals have been made to develop a common conceptual framework for deriving chemical footprints (Rydberg *et al*. 2014). Several initiatives recognize and aim to address the need for coherence, comparability and transparency (SASB 2015; Future-Fit Foundation 2017; WBCSD

2018; GRI n.d.). Efforts at the international level to streamline approaches and facilitate coherence are under way, including in the framework of the Life Cycle Initiative (UNEP 2017), the Society of Environmental Toxicology and Chemistry (2018) and the EU Product Environmental Footprint.

### The role of metrics and reporting in chemicals and waste management beyond 2020

Despite the wide use of metrics and reporting, little of the information gathered currently feeds into international chemicals and waste frameworks such as SAICM. Stakeholders may wish to consider whether, and to what extent, the integration of such reporting could help to evaluate progress under a future platform for sound management of chemicals and waste beyond 2020.

Of equal interest may be the question of how efforts at the international level could help increase the visibility of sustainability reporting efforts, while at the same time holding stakeholders accountable. It could be worthwhile to consider mechanisms for bringing together the sustainability reporting schemes of the chemical industry and relevant downstream sectors, respective external partners and independent bodies to facilitate sharing of lessons learned, and to identify steps towards increased coherence (along with transparency). This could facilitate collaboration in order to accelerate progress towards the sound management of chemicals and waste.

## 7.5 Potential measures to advance sustainability metrics and reporting

Private sector metrics and reporting are proliferating and have significant potential to complement existing mechanisms in a beyond 2020 framework. Nevertheless, further efforts may be needed to align approaches, ensure that reporting is meaningful, increase transparency, and address the lack of a common green/sustainable chemistry assessment framework. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to further advance sustainability metrics and reporting:

- Integrate chemicals and waste considerations into existing sustainability metrics and reporting systems, where needed, and ensure that all stages of the life cycle are covered.
- Explore the need for harmonized/aligned metrics and reporting standards at relevant levels (e.g. at the sectoral level), drawing on existing international standards.
- Scale up the use of sustainability reports in all chemical and downstream industries, including through use of harmonized methods and indicators at the relevant levels (e.g. sectoral).
- Ensure that reporting is carried out using quality standards, and use, where appropriate, external reviewers and independent certification.
- Bring together relevant stakeholders to advance a common understanding of metrics, including exploring potential elements of a practical guidance on sustainable chemistry.
- Encourage investors to systematically take into account sustainability reporting in their investment decisions.
- Consider ways that relevant metrics and reporting can play a more formal role in measuring progress in order to implement the 2020 goal for the sound management of chemicals and waste.

# 8/ Empowering and protecting citizens, workers and consumers

## Chapter Highlights

Citizens play a key role in shaping demand for safer and more sustainable products, and in shaping relevant policies and action by governments and the private sector.

Providing workers, consumers and communities with access to chemical information is a requisite for implementing the public's right-to-know, and for ensuring effective public participation.

New information tools and mobile applications are available to engage citizens in collecting and processing knowledge relevant to chemicals and waste management.

Use of human rights laws may complement other legislation to advance the sound management of chemicals and waste, and to ensure protection or seek remedies.

Research and policy development within the framework of the Human Rights Council suggests that human rights violations have been caused by chemical pollution.

A number of leading chemical companies have embraced a human rights approach in advancing sustainability.

The management of chemicals and waste is complex and often highly technical. Specialists, including toxicologists and risk managers, are at the forefront of decision-making. Yet workers, consumers, citizens and institutional purchasers also have important roles to play in advancing sound chemicals and waste management. They can stimulate market transformation through their purchasing decisions, participate in decision-making and, when necessary, access the courts.

## 8.1 The role of citizens and consumers in shaping markets and policies

### Consumer awareness can drive market transformation

Consumers can have a major impact through purchasing products with desirable environmental properties (OECD 2018). By means of their purchasing decisions, consumers are able to influence the chemical content and other characteristics of products placed on the market. While ethical-value products were once a niche with a small consumer base, mainstream consumer demand has been increasing for products associated with environmental and social responsibility and sustainability (Caruana and Chatzidakis 2014). Unilever, one of the world's largest consumer goods companies, reports that its sustainable brands (which it describes as combining "a strong purpose delivering a social or environmental benefit") grew 40 per cent faster than the rest of its business in 2016 (Hancock 2017).

Consumers weigh environmental, social and economic benefits when they shop for "green" products (Maniatis 2016). Other important factors include a consumer's green self-identity and peer influence (Khare 2015). Shopping decisions are also determined by the impacts they are likely to have in the future (Buerke *et al*. 2017). Women have a particularly influential role to play, as they control the large majority of consumer spending (Silverstein and Sayre 2009). When awareness of products' health and environmental impacts influences consumer choices, this suggests that information dissemination (and access to information) can lead to more responsible consumer behaviour (Scherer, Emberger-Klein and Menrad 2017).

## The chemicals and waste dimension of consumer choices

Today consumers are more sensitive to environmental, social and ethical concerns than at any time in the past (BCG 2017). In East-Central Europe the health effects of chemicals have been ranked fourth among environmental concerns, with some one-third of the population interested in receiving more information about this topic (Luca *et al*. 2018). In many countries there has been a steady increase in the number of consumers concerned about health and wellness, as well as the short-term and long-term effects of chemicals in food (Deloitte, Food Marketing Institute and Grocery Manufacturers Association 2016; Nielsen 2016; International Food Information Council [IFIC] Foundation 2018). Food manufacturers, retailers and restaurant chains have responded to such concerns by reformulating products to eliminate the use of artificial colouring and flavouring, among other initiatives. However, redesigning products and marketing them can be a longer and far more expensive process than many consumers are aware of, while a newly introduced product

(or one with different ingredients) may not be popular with some traditional customers (Klara 2018).

In the IFIC Foundation's most recent annual Food and Health Survey, 59 per cent of respondents said it was important for the foods they purchase and consume to be produced in a sustainable way, compared with 50 per cent in 2017. The respondents also indicated that their two most important individual factors with respect to sustainability were reducing the use of pesticides, followed by ensuring an affordable food supply. In addition, when asked which sources of information most influenced their opinions on food safety issues, only 16 per cent of those aged 18 to 34 cited news articles or headlines, compared with 44 per cent of those aged 65 and older (IFIC Foundation 2018).

### Understanding factors that affect consumer behaviour

Consumers in selected developing countries expressed greater concern about the environmental impact of their consumption patterns than did those in some higher-income countries (National Geographic and Globescan 2014). "Green" consumers in India were willing to support environmental protection and accept environmental responsibilities and were inclined to look for green product-related information (Kumar and Ghodeswar 2015). In many countries price is an important factor, even when there is a preference for green products (Drozdenko, Jensen and Coelho 2011; Biswas and Roy 2015; Hancock 2017). Pro-environmental attitudes are not automatically converted into green purchasing behaviour if this means paying a considerable premium or settling for poorer performance (Olson 2013). At the same time, economic benefits or efficacy issues normally outweigh social or environmental benefits in purchasing decisions (O'Rourke and Ringer 2016). Nevertheless, in a recent survey in the United States more than half of consumers said they would drive a greater distance (up to 14 miles) and pay more (up to 19 per cent) in order to shop at a "responsible store" (American Family Life Assurance Company of Columbus and American Family Life Assurance Company of New York 2017).

At a time of rapid environmental and social change, younger consumers are playing an important role in market transformation. According to a recent survey, 92 per cent of millennials are more likely to buy products from ethical companies, while 82 per cent believe ethical brands outperform those of similar companies that lack a commitment to ethical principles (Shewan 2017). Some companies have responded to consumer concerns by adopting better sustainability practices and transparency in their value and supply chains (BCG 2017; Unilever 2018). Behavioural insights can help policymakers obtain a better understanding of the behavioural mechanisms that contribute to environmental problems, and design and implement effective policy interventions to encourage more sustainable consumption, investment and compliance decisions by both individuals and firms. The policy areas in which behavioural sciences have been integrated include water and food consumption and waste management (OECD 2017).

According to a recent UNIDO report, while consumers are influenced by the medium- and long-term savings associated with the consumption of more energy-efficient products, they do not always shift their preferences to goods with a lower environmental footprint fast enough to decouple economic growth and environmental degradation. In that report three stages in the purchasing of an environmental good are identified: 1) consumers become aware of the environmental threat and are eager to help mitigate it through their consumption choices; 2) they obtain information about the impact of environmental goods on the environment; and 3) they buy the environmental good based on their pro-environment attitude and their trust that the good will deliver the expected environmental impact. However, at all three stages the following biases may affect consumer behaviour: too little public awareness about the seriousness of the impending environmental threat; lack of information about products, costs and, in some cases, potential savings; and perceptions that companies may make exaggerated claims or even lie about their products' environmental attributes (UNIDO 2017, pp. 19-20).

## 8.2 Procedural environmental rights: exploring the chemicals and waste dimension

To empower citizens, consumers, workers and the public, through informing them and engaging them in environmental actions, individual countries as well as several international bodies have promulgated a range of policy measures, also referred to as "procedural environmental rights" (Peters 2018). An early measure taken at the international level was the adoption of Principle 10 of the Rio Declaration at the UN Conference on Environment and Development in 1992. Principle 10 states that "Environmental issues are best handled with the participation of all concerned citizens, at the relevant level. At the national level, each individual shall have appropriate access to information concerning the environment that is held by public authorities, including information on hazardous materials and activities in their communities, and the opportunity to participate in decision-making processes. States shall facilitate and encourage public awareness and participation by making information widely available. Effective access to judicial and administrative proceedings, including redress and remedy, shall be provided."

The first treaty to address procedural environmental rights was the UNECE Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (or the Aarhus Convention), which entered into force in 2001. Most recently, the 2018 Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean (the Escazú Agreement) was adopted. Its purpose is to guarantee full and effective implementation of the rights of access to environmental information, public participation and access to justice in environmental matters. It is the first treaty in the world to include specific provisions to ensure a safe and enabling environment for environmental human rights defenders (UN 2018a). Although the scope of these agreements is broader in scope than

chemicals and waste management, they support chemicals and waste management actions under topics such as labelling of chemicals, providing communities with data on chemical releases by major facilities in their vicinity, and accessing the courts when citizens' rights to a healthy environment have been violated.

## 8.3 Advancing sound management of chemicals and waste through the right-to-know

Sustainable Development Goal (SDG) Target 4.7 specifically aims to ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including through education for sustainable development and sustainable life styles, which will enable citizens to take informed decisions (UNESCO 2017). If citizens are to develop knowledge and make informed choices, the right-to-know about chemicals and waste is a key factor. It is also an important market mechanism. Several studies have shown that mandatory disclosure of information can have an impact on consumer behaviour and health (Mathios 2000).

Under the right to information, people have a right-to-know whether they are, or may be, exposed to hazardous chemicals. Right-to-know is essential in order to give effect to other rights, such as the right to participate in decision-making and policymaking, due process, and the right to an effective remedy. To realize the right to information, information about the potential impacts of substances must be available, accessible, functional and non-discriminatory (United Nations Special Rapporteur on Human Rights and Toxics [UN Special Rapporteur] 2016a).

### International environmental agreements advancing right-to-know

A number of international chemicals and waste agreements have provisions to advance right-to-know. The Minamata Convention on Mercury is a recent expression of the principle that information about chemicals and hazards belongs in the public domain. It includes several provisions about access to information, public registries, environmental education and awareness, and public participation. It also provides that information relating to the health and safety of people and the environment shall not be considered confidential. The Minamata Convention is consistent with the Aarhus Convention, which specifically provides that commercial confidentiality cannot be used as grounds for refusal to disclose information about emissions to the environment. Negotiated through a multi-stakeholder process, the SAICM Overarching Policy Strategy (OPS) adopted in 2006 includes a range of provisions striking a balance between the disclosure of information and protecting legitimate, legally protected interests (Box 8.1).

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, which entered into force in 2004, also provides for the right-to-know through public awareness and outreach activities. Other relevant measures in the Convention include the prior informed consent (PIC) procedure, the need for export notifications for substances that are not listed to Annex III (providing parties with information on chemicals coming through their borders), as well as the requirements set out under Article 13 of the Convention, which require labelling (to ensure adequate availability of information with regard to risks and/or hazards to human health or the environment) and the inclusion of a safety data sheet (for occupational purposes).

Both the Aarhus Convention and the 2018 Escazú Agreement establish an enforceable right to access environmental information, including information on chemicals and waste management. Outside these two regions, there are general freedom of information acts in many countries with enforcement provisions in the spirit of Article 19 of the Universal Declaration of Human Rights ("Everyone has the right to freedom of opinion and expression; this right includes freedom to hold opinions without interference and to seek, receive and impart information and ideas through any media and regardless of frontiers.").

**Box 8.1** **Excerpts from paragraph 15 of the SAICM Overarching Policy Strategy (OPS) (UNEP 2015)**

"The objectives of the Strategic Approach [to International Chemicals Management] with regard to knowledge and information are:

A. To ensure that knowledge and information on chemicals and chemicals management are sufficient to enable chemicals to be adequately assessed and managed safely throughout their life cycle;

B. To ensure, for all stakeholders:
   1. That information on chemicals throughout their life cycle, including, where appropriate, chemicals in products, is available, accessible, user-friendly, adequate and appropriate to the needs of all stakeholders. Appropriate types of information include their effects on human health and the environment, their intrinsic properties, their potential uses, their protective measures and regulation;
   2. That such information is disseminated in appropriate languages by making full use of, among other things, the media, hazard communication mechanisms such as the Globally Harmonized System of Classification and Labelling of Chemicals and relevant provisions of international agreements;

C. To ensure that, in making information available in accordance with paragraph 15 (b), confidential commercial and industrial information and knowledge are protected in accordance with national laws or regulations or, in the absence of such laws or and regulations, are protected in accordance with international provisions. In the context of this paragraph, information on chemicals relating to the health and safety of humans and the environment should not be regarded as confidential ...."

## National and sub-national right-to-know

Laws around the world provide for public access to information held by public authorities. These laws can often be used to gain access to information about chemicals and waste management. Where countries do not have such provisions, they can adopt them pursuant to Guideline 15 in the UNEP Guidelines for the Development of National Legislation on Access to Information, Public Participation and Access to Justice in Environmental Matters (the Bali Guidelines), adopted by the UNEP Governing Council in 2010. Guideline 15 establishes that "States should ensure that any natural or legal person who considers that his or her request for environmental information has been unreasonably refused, in part or in full, inadequately answered or ignored, or in any other way not handled in accordance with applicable law, has access to a review procedure before a court of law or other independent and impartial body to challenge such a decision, act or omission by the public authority in question."

An example of right-to-know schemes advanced at the sub-national level is Proposition 65 (or the Safe Drinking Water and Toxic Enforcement Act of 1986), promulgated in the State of California in the United States (California Office of Environmental Health Hazard Assessment 2013). It requires businesses in California to provide warnings about significant exposures to chemicals in products, homes or workplaces, or those released to the environment, that cause cancer, birth defects and other types of reproductive harm. This enables people living in that state to make informed decisions about their exposures to these chemicals. Proposition 65 requires California to publish a list (updated once a year) of such chemicals. It has grown to include approximately 900 chemicals since it was first published in 1987.

## Providing chemical product information: consumers' right-to-know

An example of consumers' right-to-know is a provision under the European REACH

(Registration, Evaluation, Authorisation and Restriction of Chemicals) Regulation. For substances of very high concern (SVHC) on a "candidate list", consumers have the right to receive information from the suppliers of an article about the presence of any SVHC in that article, and the supplier is obliged to provide the information within 45 days (Klaschka 2017). Box 8.2 describes the US EPA's Chemical Access Data Tool.

While initiatives like the one under REACH support consumers' right-to-know, some consumers may not be capable of using information about hazardous substances in products adequately, even if they have a high educational level. Consumers may also assume, wrongly, that products with eco-labelling, natural personal care products or products without hazard pictograms do not contain harmful substances. Organic food or untreated food, homeopathic medicines and natural personal care products may all contain harmful substances (Klaschka 2016; United States Food and Drug Administration 2017). An enhanced strategy to communicate chemical risks in consumer products may be thus warranted, including extensive participation by target groups. Furthermore, greater efforts by authorities and manufactures are important in building trust and providing easily understandable information (Hartmann and Klaschka 2017).

### Providing chemical pollution information to the public: community right-to-know

Community right-to-know provisions help increase the public's knowledge and access to information on chemicals at individual facilities, as well as their uses and releases to the environment. These provisions allow public concerns to be addressed regarding environmental and safety hazards due to the storage, handling and emissions of toxic chemicals in the vicinity of industrial installations.

The public's right-to-know about chemicals and waste is greatly enhanced by the use of structured, accessible databases, such as Pollutant Release and Transfer Registers (PRTRs), which enable informed participation in environmental decision-making. PRTRs collect and provide information on chemicals released to the environment or otherwise managed as waste. They support the public's right-to-know and provide useful information for evaluating the performance of facilities, sectors and governments (Wine *et al.*

**Box 8.2** **The US EPA's Chemical Access Data Tool (US EPA 2017)**

The Chemical Data Access Tool (CDAT) provides a range of chemical-specific information submitted to the United States Environmental Protection Agency (US EPA) under the Toxic Substances Control Act (TSCA). The CDAT enables searches of the following databases:

- The CDR database includes non-confidential information on the manufacture (including import), processing and use of chemicals reported under the Chemical Data Reporting (CDR) rule.
- The eDoc database includes a broad range of health and safety information reported by industry under TSCA Sections 4, 5, 8(d) and 8(e).
- The TSCA Test Submissions (TSCATS) database is an online index to unpublished, non-confidential studies covering chemical testing results and adverse effects of chemicals on health and ecological systems.
- The High Production Volume Information System (HPVIS) database provides access to health and environmental effects information obtained through the High Production Volume (HPV) Challenge.
- The declassified CBI database includes health and safety studies, and other information, submitted to the EPA in which chemical identities have been declassified as part of its effort to increase transparency in TSCA.

2014). An early example was the Toxics Release Inventory under the Emergency Planning and Community Right-to-Know Act in the United States.

Many countries, including in low- and middle-income regions, subsequently introduced PRTRs. Chile's PRTR, for example, contains accessible information through a website including a FAQ page in Spanish and English that explains the sources of air and water pollutants, their impact on health and how they can be avoided, among other information (Registro de Emisiones y Transferencias de Contaminantes n.d.). While China does not have a PRTR system in place, it established a set of Open Environmental Information measures in 2008 requiring local governments to disclose information on, among others, environmental laws and regulations; the allocation of emission quotas and permits; pollution fees and penalties collected; and lists of violators of environmental regulations. These measures have given citizens the ability to request information, leading to greater NGO participation in environmental governance (although with limited impact) (Tan 2014). Such initiatives could provide a good starting point for developing a PRTR or similar system.

The private sector also plays an important role in advancing communities' right-to-know. The ZDHC Group, for example, is a coalition of textile, leather and footwear industries and related chemical industry and other solution providers that supports the improvement of chemicals management and the development of publicly available indicators throughout the apparel and footwear supply chains to reduce discharges of hazardous chemicals to the environment. ZDHC member brands encourage their supply partners to proactively disclose PRTR information (ZDHC 2014; ZDHC 2018). Another important example is the Clean Electronics Production Network (CEPN) (Green America Center for Sustainability Solutions n.d. a; Green America Center for Sustainability Solutions n.d. b).

## Workers' right-to-know

Workers' right-to-know refers to their right to information about chemicals in the workplace. The ILO Chemicals Convention of 1990 (No. 170) states that "workers have a need for, and right to, information about the chemicals they use at work" and includes specific obligations in this regard. Employers can use specific measures and tools such as labelling, hazard symbols, safety data sheets and training to inform workers about chemical hazards. The United States Occupational Safety and Health Administration (US OSHA) acknowledges workers' right-to-know about hazards present in the workplace and how to protect themselves (US OSHA 2016). In Canada all employees have a right-to-know what hazards are present on the job and how these hazards can affect them (Canadian Centre for Occupational Health and Safety 2018). In Europe workers' right-to-know about workplace hazards is managed by the European Agency for Safety and Health at Work (European Agency for Safety and Health at Work 2018).

## Using the internet and apps to disseminate chemical information and knowledge

New information and communication technologies, such as mobile applications, are now available to help citizens, consumers and workers better understand the chemical composition of certain products and their potential exposure (Box 8.3). While these applications cannot replace a full risk assessment, many of them feature chemical hazard information, thus providing information about intrinsic properties of chemicals and/or information on chemicals subject to regulatory processes. This information allows users to consider a range of possible measures. For example, after a consumer using the Toxfox app sent a SVHC information request for a bicycle care set to the sporting goods manufacturer Decathlon, the company discontinued sales of the product, which contained the hazardous plasticizer Bis(2-ethylhexyl) phthalate (DEHP) (LIFE AskREACH 2018).

**Box 8.3** **Examples of mobile applications for disseminating chemical information**

- ToxFox, a smartphone app by Friends of the Earth Germany, provides information about endocrine-disrupting chemicals in cosmetics and allows users to submit SVHC inquiries. It has a continuously growing database, in which suppliers' responses are saved. Suppliers can also enter data about the SVHC content of their articles (Klaschka 2017).

- The AskREACH mobile app, similar to ToxFox, is scheduled to be launched in April 2019. It will be available throughout Europe and may be adapted for use in each EU Member State (Lovell 2018).

- The Dirty Dozen app helps consumers determine which fruits and vegetables are best bought organic by identifying those with maximum pesticide residues. Another app for food is EWG's Healthy Living app, which allows users to scan a product, review its rating and buy the better, healthier choice (Sammons 2016).

- For cosmetics and personal care products, apps such as Cosmetifique and Think Dirty allow consumers to make better beauty choices by listing potentially toxic ingredients when they scan a product and even to find cleaner alternatives to toxic products (Sammons 2016).

- GoodGuide provides consumers with product information to help guide more informed buying decisions. Products are assessed by a team of over 50 scientific and regulatory professionals with expertise in chemicals and chemical-containing products. The team includes chemists, toxicologists, and life cycle assessment and regulatory experts (GoodGuide 2019).

While these apps are evolving, information is still scattered and it may not be easy to find comprehensive information. A user-friendly, central coordinated information hub could be helpful in raising awareness and enabling citizens to easily find comprehensive information from scatted sources.

**Figure 8.1** DOZN scoring example (adapted from Sigma-Aldrich 2018)

**Beta-amylase**

| Principe | % improvements | Remarks |
|---|---|---|
| 1. Waste prevention | 55 | Eliminated organic solvent usage and reduced overall waste generation by 50% |
| 2. Atom economy | 52 | Increased yields and reduced amount of raw materials used |
| 3. Less hazardous synthesis | 96 | Replaced organic solvents with water-based solutions and removes toxic filtering agents |
| 5. Safer solvents | 100 | Eliminated all organic solvent usage |
| 6. Energy efficiency | 100 | New process eliminated need for elevated temperature and pressure |
| 7. Renewable feedstock | 71 | More efficient environmental impact with new procedure |
| 10. Design for degradation | No change | No increased environmental impact with new practice |
| 12. Accident prevention | 54 | Eliminated flammability and reactivity dangers |
| **Total** | **95%** | |

| **Aggregate score** | Previous process | Re-engineered process |
|---|---|---|
| | 43 | 2 |

**Scoring matrix** (0 = most desirable): 100 … 0

DOZN (Quantitative Green Chemistry Evaluator) is an interactive web-based scoring matrix based on the 12 Principles of Green Chemistry which allows users to calculate the relative greenness of chemical products and processes (ACS Green Chemistry Institute 2017).

## 8.4 Public participation in chemicals and waste management

International agreements, statutory legislation and public bodies around the world are providing the public with rights and opportunities to contribute to and participate in decision-making related to the environment, including with respect to chemicals and waste management. The requirement to assess the environmental impacts of a proposed project as part of a permitting process has become a global standard. As part of this assessment, it is generally considered necessary to provide for public participation. The UNECE Convention on Environmental Impact Assessment in a Transboundary Context (the Espoo Convention), which entered into force in 1997, and the UNECE Aarhus Convention together establish a good international standard for public participation in environmental decision-making.

### Public participation in chemicals management

The European Chemicals Agency, for example, organizes public consultations to obtain feedback from interested parties and gather the widest possible range of scientific information for regulatory processes. This includes public consultations for making the final decision on which substances cannot be placed on the market, or used after a given date, unless they meet specific authorization requirements (ECHA 2018). The US EPA has public participation processes for certain pesticide registration actions as part of its Pesticide Program, providing an opportunity for the public to comment on risk assessments and proposed registration actions (US EPA 2018). In China citizens increasingly make use of information communication technologies, such as social media and blogging websites, to further citizen participation in environmental sustainability initiatives and influence governmental decision-making (He *et al.* 2017). In Canada, under the Chemicals Management Plan, there are opportunities for the public and interested stakeholders to provide comments and relevant information on risk assessments and risk management measures (regulations, pollution prevention planning notices, codes of practice and guidelines) developed under the Canadian Environmental Protection Act, 1999

(Government of Canada 2016; Government of Canada 2017).

Public participation in private sector initiatives is important and evolving. Under the International Council of Chemical Associations (ICCA) Responsible Care® programme, senior executives of member organizations sign the Responsible Care® Global Charter, which is a public commitment to sound chemicals management globally through enhancing the organization's environmental, health, safety and security performance. Through the Global Charter organizations also commit to engage stakeholders along the value chain and within their communities. In addition, members commit to respond to community concerns about operations and chemicals; report information on relevant chemical-related health or environmental hazards promptly to appropriate authorities, employees, customers and any affected sectors of the public, as well as recommending protective measures; and increase knowledge through conducting and supporting relevant research on the safety, health and environmental effects of products, processes and waste materials, among others (ICCA 2015; Chemical & Allied Industries' Association 2017).

Initiatives triggered from within civil society are an important aspect of public participation. In 2015, for example, NGOs from 15 countries convened and developed the Chemical Challenge to the Global Electronics Industry (GoodElectronics 2015). More than 200 civil society groups and activists from electronics production countries and from across the globe challenged the electronics industry to improve its actions on chemicals management during the production process. In response, leading electronics companies are now working with NGOs in the Clean Electronics Production Network (CEPN) with the goal of eliminating workers exposures to hazardous chemicals.

### Use of social media to advance public participation

Social media have become platforms where consumers, end users and NGOs can share information about how a product is manufactured and sold, as well as the materials and chemicals used in the product or during its manufacture. On Facebook and LinkedIn a number of groups share views and information on toxic chemicals and sustainable chemistry. As major users of social media, 61 per cent of millennials think social media is the "new power of youth" and 70 per cent consider it a force for change (Euro RSCG Worldwide 2011). With the rise of "complaint-vertising" it has also become common for users to make their complaints known on social media, and these complaints may go viral (Eisenhardt 2015). Companies have struggled with the right way to respond to complaint-vertising; social media are therefore steering companies towards sound management of chemicals that goes beyond compliance (Sanders 2017).

As participants in environmental governance, citizens may exchange information, especially in the Information Age. Through direct communication they can extend their influence towards shaping policies (Soma *et al*. 2016). An example of social media supporting chemical risk management actions is the banning of plastic microbeads in various products. In the United States, for example, after it emerged through social media that 8 trillion microbeads entered aquatic habitats in that country per day, public support for a ban on microbeads grew, leading to prohibition of the selling and distribution of products containing them (Imam 2015). Similarly, through a social media campaign 385,000 people signed a petition by Greenpeace urging the United Kingdom (UK) Government to ban microbeads (Casson 2017), leading to a ban on microplastics in that country (Carrington 2018). More broadly, NGOs in more than 30 countries worked on or helped to pass legislation to ban microbeads in personal care products using social media (Rochman *et al.* 2015), motivating cosmetic companies to use alternatives (Conick 2018).

### Participation by citizens and workers in scientific knowledge generation

"Citizen science", sometimes also referred to as "community science" or "public participation in scientific research", is a growing movement that enlists the public in scientific discovery, monitoring and experimentation across a wide range of disciplines (Theobald *et al.* 2015). There is growing evidence that citizen science projects can achieve gains in knowledge and increase public awareness of the diversity of scientific research (Bonney *et al.* 2016). One concern about citizen science projects is data quality; however, it has been shown that participants can provide accurate and complete information as long as scientists have a sufficiently flexible or inclusive view of a citizen scientist's role (Wiersma, Parsons and Lukyanenko 2016).

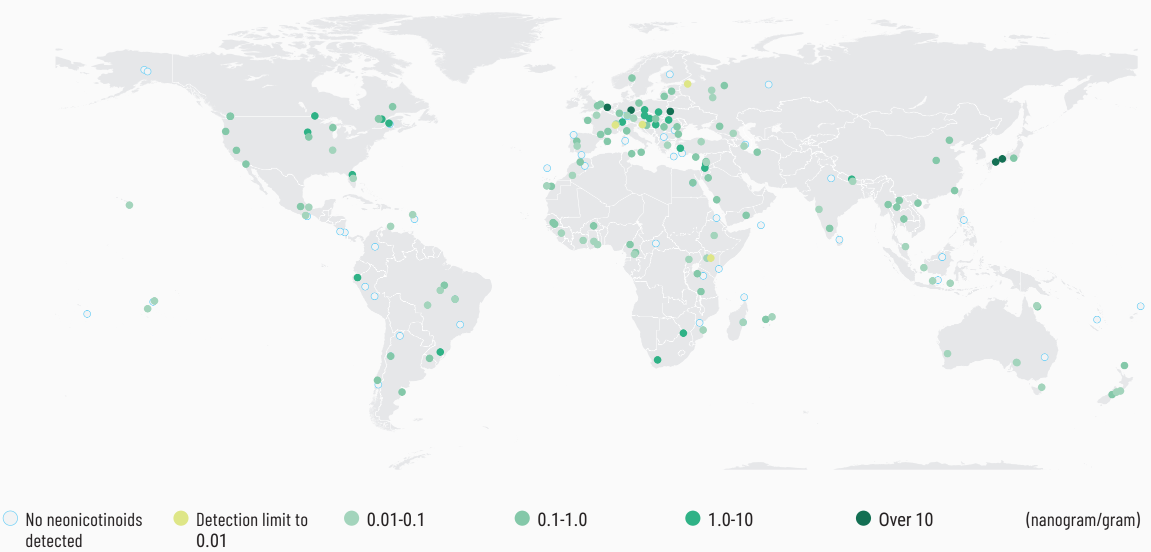
As a part of a citizen science project to monitor concentrations of neonicotinoids in honey, researchers in Switzerland analyzed honey brought back by travellers from various world regions (Mitchell *et al.* 2017) (Figure 8.2). The International Coastal Cleanup is another example of a citizen science project. Volunteers around the world collect debris from local beaches and tally it using the Ocean Conservancy's standardized data format (Zettler *et al.* 2016). A collaborative effort between researchers at Washington State University in the United States and a small town is an example of community involvement in waste management research and decision-making (Youngquist *et al.* 2015). In Contra Costa County, California, citizens used low-cost air monitoring technology based on the use of inexpensive plastic buckets to measure emissions from a local petroleum refinery in view of lack of support from the US EPA. Similar citizen action groups have used these buckets to collect and validate data about exposures, and the buckets have been approved as a reliable source of data for exposures (Joyce and Senier 2017).

Workers, too, can contribute to data collection. Based on data collected from silicone-based wristband passive samplers worn by fire fighters, a study revealed that the fire fighters could be exposed to VOCs and risk management was undertaken (Santiago *et al.* 2018). Real-time toxic gas detection during working hours may be carried out using a smartphone coupled hand-held array reader. Signals from a colorimetric reader can be transferred to a smartphone, where an app displays the detected toxic gases and their exposure levels (Devadhasan *et al.* 2017).

## 8.5 Access to justice in chemicals and waste management

Access to justice is a basic principle of the rule of law. In the absence of access to justice, people are unable to make their voices heard,

**Figure 8.2** **Citizen science project to monitor the concentration of neonicotinoids in honey, November 2012 and February 2016 (adapted from Mitchell *et al.* 2017, p. 110)**



exercise their rights, challenge discrimination or hold decision-makers accountable (UN 2018b). Access to justice helps ensure public authorities' accountability to the public. It also provides the public with assured final recourse to justice with a view to ensuring correct implementation of environmental law (Pan-European Coalition of Environmental Citizens Organisations 2016).

Under Article 9.1 of the Aarhus Convention, Parties have agreed on standards for access to justice in respect to information requests. For example, a person does not need to show an interest in the information requested in order to have standing to challenge a refusal to provide the information in whole or in part. The Convention is also concerned with matters of judicial administration, including costs, fairness and timeliness. Similarly, members of the public whose rights to participate in environmental decision-making are not respected have the option to seek access to justice under Article 9.2 of the Aarhus Convention. The same principle is expressed in the UNEP Bali Guidelines (Guideline 16) as follows: "States should ensure that the members of the public concerned have access to a court of law or other independent and impartial body to challenge the substantive and procedural legality of any decision, act or omission relating to public participation in decision-making in environmental matters."

### Access to justice in matters of law enforcement

Public concern about the environment, human health and exposure to chemicals, and other hazards and risks, can be harnessed to help public authorities enforce environmental laws. This role is contained within the Aarhus Convention (Article 9.3), the Escazú Agreement (Article 8.2(c)) and the Bali Guidelines (Guideline 17). Such provisions give the public opportunities to meet their duty to protect and improve the environment for the benefit of present and future generations, as recognized in Principle 1 of the Declaration of the United Nations Conference on the Human Environment, agreed in Stockholm in 1972. For example, in 2015 China amended its Environmental Protection Law to allow any duly registered NGO that had been engaged in



environmental protection activities for at least five consecutive years to initiate public interest environmental litigation. Before this amendment went into effect there were as few as eight cases a year, but since 2015 there have been over 117 public interest environmental cases (UNEP 2018).

### Standing requirements to access courts

Countries are increasingly recognizing the standing of environmental civil society organizations to bring cases in the public interest aimed at protecting human health and the environment. Most legal systems have required that members of the public challenging such decisions meet certain standing requirements, expressed as the "public concerned." However, there is a trend towards eliminating formal requirements such as those related to the registration of organizations or of the organizations' purposes. For example, Mexico now recognizes "collective actions" by social groups that may not be legally registered (UNEP 2015). In California, Proposition 65 (the Safe Drinking Water and Toxic Enforcement Act of 1986) provides citizen standing to sue. Any individual acting in the public interest may enforce Proposition 65 by filing a lawsuit against a business alleged to be in violation of it (California Office of Environmental Health Hazard Assessment 2013). Under the Aarhus Convention, certain established environmental NGOs should be granted standing to challenge decisions even when they would not meet the strict legal interest test under some legal systems. On the other hand, under United States jurisprudence an organization must have suffered an "injury in fact" to have standing to challenge a government decision.

### Science in judicial proceedings

Judicial systems around the world have addressed the challenges presented by complex scientific considerations in environmental cases by establishing specialized courts. To expand and deepen systems of access to remedy in India, the Green Tribunal Act was passed in 2010. This Act stemmed from the 1996 *Indian Council for EnviroLegal Action v. Union of India* case, where the court stated that a system of green tribunals with jurisdiction over civil and criminal aspects of environmental claims could help achieve expediency of justice, establish panels of experts to resolve highly technical cases, and help reduce large caseloads (UNDP 2014). Other prominent examples of specialized environmental courts may be found in Australia, Chile, Kenya, Pakistan and the Philippines. Altogether at least 44 countries have some form of environmental court. The Escazú Agreement includes a reference to shifting the burden of proof in certain cases where chemicals and hazardous wastes could be involved. Article 8.3(e) refers to "measures to facilitate the production of evidence of environmental damage, when appropriate and as applicable, such as the reversal of the burden of proof and the dynamic burden of proof."

## 8.6 Human rights law with respect to chemicals and waste management

*Linkages to a range of human rights*

The use of human rights-based approaches complements and provides a back-up to legislative and regulatory measures in ensuring protection and access to effective remedies. Hazardous substances and wastes, including toxic chemicals, are associated with a broad range of civil, cultural, economic, political and social rights. Under a number of international human rights instruments, countries have a duty to protect human rights, including those threatened by the presence of hazardous chemicals and waste (UN Special Rapporteur 2016b). Every country has recognized one or more human rights that are directly or indirectly implicated by the management of chemicals and waste. For example, virtually every country has ratified the UN Convention on the Rights of the Child, which recognizes the right of the child to the highest attainable standard of health and requires that states shall take appropriate measures to combat disease and malnutrition, taking into consideration the dangers and risks of environmental pollution.

The right-to-know about possible exposures to chemicals and hazardous wastes has also been guaranteed through human rights instruments. An example is the European Convention on Human Rights, Article 8, which provides for respect for one's "private and family life, his home and his correspondence." In *Guerra v. Italy* the Court interpreted Article 8 in a case where authorities had failed to provide information about the risks associated with a chemical factory or about emergency procedures. It affirmed that severe environmental pollution could interfere with the right to respect for home, private life and family and held that the authorities had not taken the necessary measures to ensure effective protection of this right by providing essential information. A similar result was reached in the Inter-American Court of Human Rights in the case of *Claude-Reyes v. Chile.* In interpreting Article 13 of the American Convention on Human Rights, which addresses the right to freedom of expression (Inter-American Commission on Human Rights 2011), the Court held that this right includes the right of the public to have access to State-held information, as well as the State's obligation to provide the information subject to limited exceptions. Thus, the failure of a State body to disclose information on environmental matters requested by an NGO violates Article 13 of the American Convention on Human Rights.

### The right to a healthy environment

A large majority of UN Member States have constitutional provisions that include the right to a healthy environment in some form, which can be considered an economic, social or cultural right.

As elaborated in Stockholm Principle 1 adopted in 1972, the natural environment is essential to the enjoyment of basic human rights and the right to life itself. Violations of environmental rights may have a profound impact in regard to a wide variety of human rights, including those to life, self-determination, food, water, health, sanitation, housing, and other cultural, civil and political rights.

Enforcing such rights has traditionally presented challenges, but recently certain developments in international jurisprudence have clarified that they are capable of direct enforcement (Box 8.4).

**Box 8.4** **Cases of human rights protection in matters of chemicals and waste**

The use of environmental rights and human rights to obtain protection or seek remedies related to chemicals and waste is widespread. Examples include:

- In Mexico, the Comisión Nacional de los Derechos Humanos (CNDH) issued a number of recommendations related to environmental protection even before the right to a healthy environment was included in the Mexican Constitution in 2012. In 2010 CNDH found that the National Water Commission did not comply with environmental standards, which caused the death of a child and affected the health of people living in the vicinity of the Santiago River. It recommended that the National Water Commission warn residents of the risk of pollution and take steps to clean up and restore the affected areas (Environmental Rights Database [ERDb] n.d. a).
- The Supreme Court of India has been active in protecting the right to life from environmental degradation. It ordered the closing down of limestone quarries and mining operations, among others, to protect citizens' right to life (ERDb n.d. b).
- In the United Kingdom, the Trafigura waste dumping case is an example of justice successfully accessed for crimes committed abroad. A group action by approximately 30,000 claimants from Côte d'Ivoire against Trafigura Ltd. was heard by the High Court of Justice in London in 2006. In 2009 the parties reached a settlement, with Trafigura agreeing to pay each claimant approximately US dollars 1,500 (A/HRC/36/41/Add.1).

A recent case is *Lagos del Campo v. Peru* of 2017 in the Inter-American Court of Human Rights, the first decision of that court which recognized the direct enforceability of economic, social or cultural rights. In this case the subject right was the right to work (International Network for Economic, Social & Cultural Rights 2018). Even in federal systems where there is no such right at the constitutional level, many constituent states, provinces or republics establish such rights in their own laws.

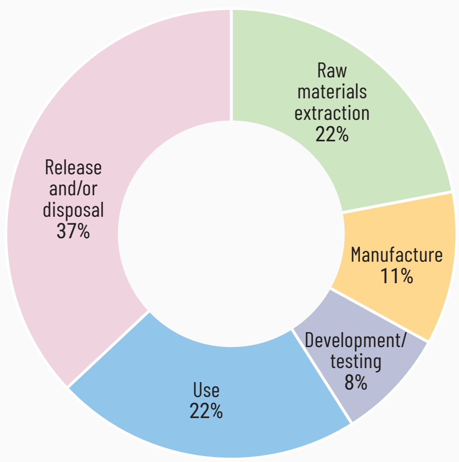
### UN Human Rights Council initiatives and appointments

Since 1995 the Commission on Human Rights and its successor, the Human Rights Council (HRC), have mandated a Special Rapporteur to report on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes. While the Commission on Human Rights mandate in 1995 covered waste, the HRC expanded the mandate in 2011 and appointed a UN Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes. The mandate includes monitoring and reporting on the human rights impacts of such substances throughout their life cycle, including production, management, handling, distribution and final disposal.

In 2011 the HRC affirmed "that the way hazardous substances and wastes are managed throughout their lifecycle, including manufacturing, distribution, use and final disposal, may have an adverse impact on the full enjoyment of human rights". Similarly, the Special Rapporteur has emphasized that the right to information on hazardous substances and wastes is central to the enjoyment of human rights and fundamental freedoms. He also makes the case that information should be available, accessible and functional for everyone, consistent with the principle of non-discrimination (United Nations Human Rights Council [UN HRC] 2015; Office of the United Nations High Commissioner for Human Rights 2018).

Research recently undertaken within the mandate of the Special Rapporteur suggests that human rights violations and abuses caused by chemical pollution are still prevalent. A UK-based non-profit, the Business & Human Rights Resource Centre (BHRRC), has collaborated with the UN Special Rapporteur to analyze trends concerning alleged cases of human rights abuse relating to the chemical industry, along with responses by States and companies. The analysis notes that despite positive steps to address toxic pollution from the chemical industry, critical gaps remain, particularly in protecting the rights of workers, children, low-income communities and other vulnerable groups. Figure 8.3 shows human rights impacts by life cycle stage, as identified

**Figure 8.3** **Human rights impacts by life cycle stage, information received between 2012-2017 (adapted from BHRRC 2018, p. 3)**



in the report. It concludes by recommending that States and businesses strengthen chemical industry regulations and practices in line with human rights standards (BHRRC 2018).

In an August 2018 report to the HRC, the Special Rapporteur recommended that "States must ensure that legislation and other practices reflect their duty to respect, protect and fulfil human rights obligations implicated by hazardous substances and wastes [...] [and] that victims of the effects of hazardous substances and wastes have access to an effective remedy", further noting that "the right to information is critical in the context of toxics". This report sets out findings from four years of monitoring in industries and countries around the world, with a focus on the situation of workers exposed to toxic and otherwise hazardous substances worldwide. It argues that many companies and national governments are not meeting their duty to uphold the rights of workers under the Universal Declaration of Human Rights and the International Covenant on Economic, Social and Cultural Rights. These stipulate the right to safe and healthy working conditions.

The report proposes 15 principles which are relevant to strengthening chemicals and waste management beyond 2020. They aim at helping governments and businesses ensure protection from exposure to hazardous chemicals, which the Special Rapporteur referred to as a global health crisis. The proposed principles broadly cover the responsibilities and duties of businesses and governments; worker access to information; and "remedies" to hold those who violate workers' rights accountable (UN HRC 2018). A subsequent report in October 2018 explored opportunities to further integrate the human rights dimension of chemicals and waste into the beyond 2020 framework.

### Corporate responsibility, accountability and human rights

The role of corporations in achieving sustainability was recognized as long ago as the World Commission on Environment and Development report *Our Common Future*, published in 1987. The corporate sustainability or corporate social responsibility movement has proceeded through various certification schemes, membership organizations, guidelines and standards, such as the ISO 26000 standards for corporate social responsibility, the Global Reporting Initiative, the Equator Principles and the UN Global Compact. In parallel, critics of the voluntary approach have advocated for the adoption of binding norms governing corporate behaviour with social and environmental impacts, largely under the rubric of corporate accountability (Antypas and Paszkiewicz 2015).

In 2008 the UN Human Rights Council adopted the UN Protect, Respect and Remedy Framework for Business and Human Rights, commonly known as "the Ruggie Framework" after the UN Special Rapporteur, Professor John Ruggie. This framework expresses the global standard of expected corporate conduct and provides the baseline for corporate responsibility with respect to human rights as "part of the company's social license to operate". It centres on three "differentiated but complementary" pillars of responsibility: the State's duty to protect against human rights abuses by third parties (including business); corporate responsibility to protect human rights; and the need for more effective access to remedies.

The Ruggie Framework was followed by the endorsement in 2011 of the UN's Guiding Principles on Business and Human Rights (Antypas and Paszkiewicz 2015). The international community indicated its commitment to these Guiding Principles through the UN General Assembly's adoption of the 2030 Agenda for Sustainable Development in 2015. In response to the adoption of these Guiding Principles, major chemical companies such as BASF and Merck have committed to protect human rights (Merck 2017; BASF 2018). Important steps companies may take to prevent and address human rights impacts related to their production and products include the use of a life cycle approach. Hence, everyone in the entire chain of a product's life cycle has a responsibility to consider the environmental, social and economic impacts of a product at every stage of its life cycle (BHRRC 2018).

## 8.7 Potential measures to empower and protect citizens, workers and consumers

The roles of citizens and consumers in advancing the sound management of chemicals and waste are crucial. Enabling policies, including the right-to-know of workers, consumers and communities, public participation, and access to justice, coupled with innovative technologies, can reap the full potential of citizens to engage and protect their rights to a healthy environment. Taking into account the preceding analysis, stakeholders may wish to consider the following measures to empower and protect workers, consumers and citizens:

- Take steps so that consumers have appropriate knowledge concerning chemicals in products in order to make informed decisions, including through innovative technology applications.
- Develop and strengthen worker, consumer and community right-to-know policies and laws, and ensure that relevant and complete information concerning hazards and possible exposures to chemicals is made available.
- Engage citizens and the public in collecting data relevant for scientific chemical analysis and effective chemicals risk management policies.
- Consider stricter regulation that requires clear and consumer-friendly advice for using harmful products in a safe way.
- Initiate corporate campaigns, multi-stakeholder collaborations, and working with socially responsible investors.
- Ensure that citizens can access the courts in matters of chemical pollution and human health protection related to chemicals and waste.
- Encourage all chemical companies to embrace the UN Guiding Principles on Business and Human Rights.

# References

## Chapter 1

Abraham, M.A. and Nguyen, N. (2003). 'Green engineering: defining the principles'- results from the Sandestin conference. *Environmental Progress* 22(4), 233-236. https://doi.org/10.1002/ep.670220410.

American Chemical Society (2019). History of green chemistry. https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/history-of-green-chemistry.html. Accessed 21 February 2019.

American Sustainable Business Council and Green Chemistry & Commerce Council (2015). *Making the Business & Economic Case for Safer Chemistry*. http://asbcouncil.org/sites/default/files/asbcsaferchemicalsreportpresred.pdf.

Anastas, P.T. and Warner, J.C. (1998). *Green Chemistry: Theory and Practice*. Oxford University Press. https://global.oup.com/academic/product/green-chemistry-theory-and-practice-9780198506980?cc=ch&lang=en&.

Anastas, P.T. and Zimmerman, J.B. (2003). Design through the 12 Principles of Green Engineering: sustainability requires objectives at the molecular, product, process, and system levels. *Environmental Science & Technology* 37(5), 94A-101A. https://doi.org/10.1021/es032373g.

Anastas, P.T. and Zimmerman, J.B. (2018). The United Nations sustainability goals: how can sustainable chemistry contribute? *Current Opinion in Green and Sustainable Chemistry* 13, 150-153. https://doi.org/10.1016/j.cogsc.2018.04.017.

BCC Research (2016). Global concerns promoting growth of 'green' chemistry markets, reports BCC Research, 4 April. *Markertwired*. http://www.marketwired.com/press-release/global-concerns-promoting-growth-of-green-chemistry-markets-reports-bcc-research-2111318.htm. Accessed 3 June 2018.

Bernick, L. (2016). The $100 billion business case for safer chemistry, 6 May. *Greenbiz*. https://www.greenbiz.com/article/100-billion-business-case-safer-chemistry. Accessed 30 January 2019.

Bhattacharjee, N. and Swamynathan, Y. (2017). Chemical giants see growth in green, clean tech, 27 July. *Reuters*. https://www.reuters.com/article/us-dupont-results-health-idUSKBN1AC2ZP. Accessed 6 August 2018.

Blum, C., Bunke, D., Hungsberg, M., Roelofs, E., Joas, A., Joas, R., Blepp, M. and Stolzenberg, H.-C. (2017). The concept of sustainable chemistry: key drivers for the transition towards sustainable development. *Sustainable Chemistry and Pharmacy* 5, 94-104. https://doi.org/10.1016/j.scp.2017.01.001.

Cayuela, R. and Hagan, A. (2019). *The Chemical Industry Under the 4th Industrial Revolution: The Sustainable, Digital and Citizens One*. Not yet published. Hoboken, NJ: Wiley-VCH Verlag GmbH.

Cisco (2017). Industry 4.0: 11 questions answered, 1 September. *Cisco Canada Blog*. https://gblogs.cisco.com/ca/2017/09/01/industry-4-0-11-questions-answered/. Accessed 3 December 2018.

Clark, J.H. (2006). Green chemistry: today (and tomorrow). *Green Chemistry* 8(1), 17-21. https://doi.org/10.1039/b516637n.

Deloitte and German Chemical Industry Association (2017). *Chemistry 4.0: Growth through Innovation in a Transforming World*. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/consumer-industrial-products/gx-chemistry%204.0-full-report.pdf.

Erythropel, H.C., Zimmerman, J.B., de Winter, T.M., Petitjean, L., Melnikov, F., Lam, C.H., Lounsbury, A.W., Mellor, K.E., Janković, N.Z., Tu, Q., Pincus, L.N., Falinski, M.M., Shi, W., Coish, P., Plata, D.L. and Anastas, P.T (2018). The green ChemisTREE: 20 years after taking root with the 12 principles. *Green Chemistry* 20(9), 1929-1961. https://doi.org/10.1039/c8gc00482j.

European Commission (1996). Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. *Official Journal of the European Comminities* L(257), 26-40. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.1996.257.01.0026.01.ENG&toc=OJ:L:1996:257:TOC.

European Commission (2017). *Germany: Industrie 4.0*. https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Industrie%204.0.pdf.

German Environment Agency (2016). Sustainable chemistry: what is sustainable chemistry? 3 May. https://www.umweltbundesamt.de/en/topics/chemicals/chemicals-management/sustainable-chemistry#textpart-1. Accessed 19 February 2019.

Hill, J., Kumar, D.D. and Verma, R.K. (2013). Challenges for chemical education: engaging with green chemistry and environmental sustainability. *Journal of the American Institute of Chemists* 86(1), 24-31. http://www.theaic.org/pub_thechemist_journals/Vol-86-No-1/Vol-86-No1-Article-5.pdf.

Jakobsen, S., Naik, K., Raberger, N. and Winkler, G. (2017). Demystifying digital marketing and sales in the chemical industry, February. *McKinsey*. https://www.mckinsey.com/industries/chemicals/our-insights/demystifying-digital-marketing-and-sales-in-the-chemical-industry. Accessed 16 September 2018.

Kirkpatrick, P. and Ellis, C. (2004). Chemical space. *Nature* 432(7019), 823-823. https://doi.org/10.1038/432823a.

Klei, A., Moder, M., Stockdale, O., Weihe, U. and Winkler, G. (2017). Digital in chemicals: from technology to impact, July. *McKinsey & Company*. https://www.mckinsey.com/industries/chemicals/our-insights/digital-in-chemicals-from-technology-to-impact. Accessed 20 September 2018.

Kümmerer, K. (2017). Sustainable chemistry: a future guiding principle. *Angewandte Chemie International Edition* 56(52), 16420-16421. https://doi.org/10.1002/anie.201709949.

Linthorst, J.A. (2010). An overview: origins and development of green chemistry. *Foundations of Chemistry* 12(1), 55-68. https://doi.org/10.1007/s10698-009-9079-4.

Mubofu, E.B. (2016). Castor oil as a potential renewable resource for the production of functional materials. *Sustainable Chemical Processes* 4(1), 11. https://doi.org/10.1186/s40508-016-0055-8.

Organisation for Economic Co-operation and Development (2012). *The Role of Government Policy in Supporting the Adoption of Green/Sustainable Chemistry Innovations*. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2012)3&doclanguage=en.

Organisation for Economic Co-operation and Development (2018). Sustainable chemistry. http://www.oecd.org/chemicalsafety/risk-management/sustainablechemistry.htm. Accessed 20 February 2019.

Philp, J.C., Ritchie, R.J. and Allan, J.E.M. (2013). Biobased chemicals: the convergence of green chemistry with industrial biotechnology. *Trends in Biotechnology* 31(4), 219-222. https://doi.org/10.1016/j.tibtech.2012.12.007.

Pike Research (2011). Green chemistry: biobased chemicals, renewable feedstocks, green polymers, less-toxic alternative chemical formulations, and the foundations of a sustainable chemical industry. *Industrial Biotechnology* 7(6), 431-433. https://doi.org/10.1089/ind.2011.1003.

Sarathy, V., Gotpagar, J. and Morawietz, M. (2017). The next wave of innovation in the chemicals industry, 5 June. *Strategy+Business*. https://www.strategy-business.com/article/The-Next-Wave-of-Innovation-in-the-Chemicals-Industry.

Sheldon, R.A. (2008). Green and sustainable chemistry: challenges and perspectives. *Green Chemistry* 10(4), 359-360. https://doi.org/10.1039/b804163f.

Stieger, G. (2015). Popcorn without fluorinated chemicals: retailer coop denmark introduces microwave oven popcorn containing no fluorinated substances in the food packaging, aims to phase out further chemicals of concern by 2017, 30 October. *Food Packaging Forum*. https://www.foodpackagingforum.org/news/popcorn-without-fluorinated-chemicals. Accessed 14 September 2018.

United Nations Environment Programme (2019). *Analysis of Stakeholder Submissions on Sustainable Chemistry Pursuant to UNEA Resolution 2/7*. http://www.saicm.org/Portals/12/Documents/meetings/OEWG3/inf/OEWG3-INF-22-Analysis.pdf.

United States Government Accountability Office (2018). *Chemical Innovation: Technologies to Make Processes and Products More Sustainable*. https://www.gao.gov/products/GAO-18-307.

World Economic Forum (2017). *Digital Transformation Initiative: Chemistry and Advanced Materials Industry*. http://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/dti-chemistry-and-advanced-materials-industry-white-paper.pdf.

Zuin, V.G. (2016). Circularity in green chemical products, processes and services: innovative routes based on integrated eco-design and solution systems. *Current Opinion in Green and Sustainable Chemistry* 2, 40-44. https://doi.org/10.1016/j.cogsc.2016.09.008.

## Chapter 2

American Chemical Society (2019a). Green chemistry: history. https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/history-of-green-chemistry.html. Accessed 21 February 2019.

American Chemical Society (2019b.). 12 Design Principles of Green Chemistry. https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/principles/12-principles-of-green-chemistry.html. Accessed 21 February 2019.

American Chemical Society (2019c). Green chemistry: education roadmap. https://www.acs.org/content/acs/en/greenchemistry/students-educators/education-roadmap.html. Accessed 21 February 2019.

Anastas, N.D. (2015). Embedding toxicology into the chemistry curriculum. In *Worldwide Trends in Green Chemistry Education*. Zuin, V.G. and Mammino, L. (eds.). Cambridge: Royal Society of Chemistry. Chapter 9. 137-156. https://doi.org/10.1039/9781782621942-00137.

Armstrong, L.B., Rivas, M.C., Douskey, M.C. and Baranger, A.M. (2018). Teaching students the complexity of green chemistry and assessing growth in attitudes and understanding. *Current Opinion in Green and Sustainable Chemistry* 13, 61-67. http://doi.org/10.1016/j.cogsc.2018.03.008.

Aubrecht, K.B., Padwa, L., Shen, X. and Bazargan, G. (2015). Development and implementation of a series of laboratory field trips for advanced high school students to connect chemistry to sustainability. *Journal Chemical Education* 92(4), 631-637. http://doi.org/10.1021/ed500630f.

Barra, R. and González, P. (2018). Sustainable chemistry challenges from a developing country perspective: education, plastic pollution, and beyond. *Current Opinion in Green and Sustainable Chemistry* 9, 40-44. http://doi.org/10.1016/j.cogsc.2017.12.001.

Beyond Benign (2019). Green chemistry education. https://www.beyondbenign.org/. Accessed 21 February 2019.

Burmeister M. and Eilks I. (2012). An example of learning about plastics and their evaluation as a contribution to education for sustainable development in secondary school chemistry teaching, *Chemistry Education Research and Practice* 13(2), 59-68. http://doi.org/10.1039/c1rp90067f.

Cannon, A.S. Finster, D. Raynie, D. and Warner, J.C. (2017). Models for integrating toxicology concepts into chemistry courses and programs. *Green Chemistry Letters and Reviews* 10(4), 436-443. https://doi.org/10.1080/17518253.2017.1391880.

Centi, G. and Perathoner, S. (2009) From green to sustainable industrial chemistry. In *Sustainable Industrial Processes*. Cavani, F., Centi, G., Perathoner, S. and Trifiró, F. (eds.). Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA. Chapter 1. 1-72. https://doi.org/10.1002/9783527629114.ch1.

CHEM21 (n.d.). Pharmaceuticals and universities working together on multi million pound project. https://www.chem21.eu/. Accessed 21 February 2019.

Clarivate (2018). ISI Web of Science. www.webofknowledge.com. Accessed 13 September 2018.

Clark, J.H. (2016). Green and sustainable chemistry: an introduction. In *Green and Sustainable Medicinal Chemistry: Methods, Tools and Strategies for the 21st Century Pharmaceutical Industry*. London: The Royal Society of Chemistry. Chapter 1. 1-11. https://doi.org/10.1039/9781782625940-00001.

Cohn, R. (2012). Taking green chemistry out of the lab and into products, 16 May. *Yale Environment 360*. https://e360.yale.edu/features/taking_green_chemistry_out_of_the_lab_and_into_products. Accessed 13 September 2018.

Collins, T. (2001). Toward sustainable chemistry. *Science* 291(5501), 48-49. http://doi.org/10.1126/science.291.5501.48

Collins, T. (2017). Review of the twenty-three year evolution of the first university course in green chemistry: teaching future leaders how to create sustainable societies. *Journal of Cleaner Production* 140, 93-110. https://doi.org/10.1016/j.jclepro.2015.06.136

Eilks, I. and Rauch, F. (2012). Sustainable development and green chemistry in chemistry education. *Chemistry Education Research and Practice* 13(2) 57-58. http://doi.org/10.1039/C2RP90003C.

Eissen, M., Bahadir, M., König, B. and Ranke, J. (2008). Developing and disseminating NOP: an online, open-access, organic chemistry teaching resource to integrate sustainability concepts in the laboratory. *Journal of Chemical Education* 85(7), 1000-1005. http://doi.org/10.1021/ed085p1000.

Ellen MacArthur Foundation (2017). Universities. https://www.ellenmacarthurfoundation.org/programmes/education/universities. Accessed 2 April 2018.

Global Network of Chemistry Centres (2016). A global network of chemistry centres. G2C2 and GCN: a new partnership, working together to further the cause of green chemistry. http://g2c2.greenchemistrynetwork.org/. Accessed 20 April 2018.

Green Chemistry & Commerce Council (n.d.). Advancing green chemistry across sectors and supply chains. https://greenchemistryandcommerce.org/. Accessed 2 January 2019.

Gross, E.M. (2013) Green chemistry and sustainability: an undergraduate course for science and nonscience majors. *Journal of Chemical Education* 90(4), 429-431. http://doi.org/10.1021/ed200756z.

Haack, J.A. and Hutchison, J.E. (2016). Green chemistry education: 25 years of progress and 25 years ahead. *ACS Sustainable Chemistry and Engineering* 4(11), 5889-5896. http://doi.org/10.1021/acssuschemeng.6b02069.

Haley, R.A., Ringo, J.M., Hopgood, R., Denlinger, K.L., Das, A. and Waddell, D.C. (2018). Graduate student designed and delivered: an upper-level online course for undergraduates in green chemistry and sustainability. *Journal of Chemical Education* 95(4), 560-569. http://doi.org/10.1021/acs.jchemed.7b00730.

Hamidah, N., Prabawati, S., Fajriati, I. and Eilks, I. (2017). Incorporating sustainability in higher chemistry education in Indonesia through green chemistry: inspirations by inquiring the practice in a German university. *International Journal of Physics and Chemistry Education* 9(1), 1-7. https://doi.org/10.12973/ijpce/79220.

Holme, T.A. and Hutchison, J.E. (2018). A central learning outcome for the central science. *Journal of Chemical Education* 95(4), 499-501. http://doi.org/10.1021/acs.jchemed.8b00174.

International Sustainable Chemistry Collaborative Centre (2018). ISC3 – International Sustainable Chemistry Collaborative Centre. https://www.isc3.org/en/home.html. Accessed 20 August 2018.

International Union of Pure and Applied Chemistry (2018). Systems thinking, and green and sustainable chemistry, 26 September. https://iupac.org/systems-thinking-and-green-and-sustainable-chemistry/. Accessed 21 February 2019.

Italian National Committee for IUPAC of the National Research Council of Italy (2016). Interdivisional Committee on Green Chemistry for Sustainable Development: mission. http://www.iupac.cnr.it/interdivisional-committee-on-green-chemistry-for-sustainable-development-icgcsd. Accessed 21 February 2019.

Juntunen, M. and Aksela, M. (2014). Education for sustainable development in chemistry – challenges, possibilities and pedagogical models in Finland and elsewhere. *Chemistry Education Research and Practice* 15(4), 488-500. http://doi.org/10.1039/c4rp00128a.

Karpudewan, M., Ismail, Z. and Roth, W.-M. (2012). Promoting pro-environmental attitudes and reported behaviors of Malaysian pre-service teachers using green chemistry experiments. *Environmental Education Research* 18(3), 375-389. http://doi.org/10.1080/13504622.2011.622841.

Kennedy, S.A. (2016). Design of a dynamic undergraduate green chemistry course. Journal of Chemical Education 93(4), 645-649. http://doi.org/10.1021/acs.jchemed.5b00432.

Kitchens, C., Charney, R., Naistal, D., Farrugia, J., Clarens, A., O'Neil, A., Lisowski, C. and Braun, B. (2006). Completing our education. green chemistry in the curriculum. *Journal of Chemical Education* 83(8), 1126 http://doi.org/10.1021/ed083p1126.

Kümmerer, K. (2017). Sustainable chemistry: a future guiding principle. *Angewandte Chemie-International Edition* 56(52), 16420-16421. https://doi.org/10.1002/anie.201709949.

Lee, K□H. (2009). Why and how to adopt green management into business organizations? The case study of Korean SMEs in manufacturing industry. *Management Decision* 47(7), 1101-1121. http://doi.org/10.1108/00251740910978322.

Leitner, W. (2004). Focus on education in green chemistry. *Green Chemistry* 6(8), 351. http://doi.org/10.1039/B412202J.

Levy, I.J. and Middlecamp, C.H. (eds.). (2015). *Teaching and Learning about Sustainability*. Washington, D.C.: American Chemical Society. http://doi.org/10.1021/bk-2015-1205.

Lozano, R. and Watson, M.K. (2013). Chemistry education for sustainability: assessing the chemistry curricula at Cardiff University. *Educación Química* 24(2), 184-192. https://doi.org/10.1016/S0187-893X(13)72461-3.

Mahaffy, P.G., Krief, A., Hopf, H., Mehta, G. and Matlin, S.A. (2018). Reorienting chemistry education through systems thinking. *Nature Reviews Chemistry* 2(4), 1-3. https://doi.org/10.1038/s41570-018-0126.

Mammino, L. (2015). A great challenge of green chemistry education: the interface between provision of information and behaviour patterns. In *Worldwide Trends in Green Chemistry Education*. Zuin, V. and Mammino, L. (eds.). Cambridge: Royal Society of Chemistry. 1-15. https://doi.org/10.1039/9781782621942-00001.

Matus, K.J.M., Clark, W.C., Anastas, P.T. and Zimmerman, J.B. (2012). Barriers to the implementation of Green Chemistry in the United States. *Environmental Science and Technology* 46(20), 10892-10899. http://doi.org/10.1021/es3021777.

Network Operations Portal (2018). Sustainability in the organic chemistry lab course, 23 May. https://www.oc-praktikum.de/nop/en-entry. Accessed 15 July 2018.

Shuang, L. and Yanqi, Z. (2018). A metrology analysis of articles published on green chemistry from 1999 to 2016. *Chemistry Bulletin* (HUAXUE TONGBAO) 81(7), 660-666. In Chinese.

Sjöström, J., Eilks, I. and Zuin, V. G. (2016). Towards eco-reflexive science education: a critical reflection about educational implications of Green Chemistry. *Science & Education* 25(3-4), 1-21. http://doi.org/10.1007%2Fs11191-016-9818-6.

Sjöström, J. and Talanquer, V. (2018). Eco-reflexive chemical thinking and action. *Current Opinion in Green and Sustainable Chemistry* 13, 16-20. http://doi.org/10.1016/j.cogsc.2018.02.012.

Summerton, L., Hurst, G.A. and Clark, J.A. (2018) Facilitating active learning within green chemistry. *Current Opinion in Green and Sustainable Chemistry* 13, 56-60. http://doi.org/10.1016/j.cogsc.2018.04.002.

United Nations Educational, Social and Cultural Organization (2014). *Shaping the Future We Want - UN Decade of Education for Sustainable Development (2005-2014) (Final Report).* https://sustainabledevelopment.un.org/content/documents/1682Shaping%20the%20future%20we%20want.pdf.

United Nations Educational, Social and Cultural Organization (2018). Education for sustainable development. https://en.unesco.org/themes/education-sustainable-development. Accessed 13 September 2018.

United Nations Industrial Development Organization (2018). Guidance development and case study documentation of green chemistry and technologies. *Open Data Platform*. https://open.unido.org/projects/M0/projects/150185?_ga=2.177078181.1470394430.1535145283-246569987.1525458642. Accessed 20 July 2018.

United States Environmental Protection Agency (2017). Pollution Prevention Act of 1990, 30 March. https://www.epa.gov/p2/pollution-prevention-act-1990. Accessed 21 February 2019.

University of Oregon (2018). The place for green. http://greenchem.uoregon.edu/. Accessed 2 May 2018.

Vallée, M. (2016). Obstacles to curriculum greening: the case of green chemistry. In *The Contribution of Social Sciences to Sustainable Development at Universities.* Filho, W.L. and Zint, M. (eds.). Cham: Springer. 245-258. https://doi.org/10.1007/978-3-319-26866-8_15.

Wang, M.-Y., Li, X.-Y. and He, L.-N. (2018). Green chemistry education and activity in China. *Current Opinion in Green and Sustainable Chemistry* 13, 123-129. http://doi.org/10.1016/j.cogsc.2018.07.001.

Welton, T. Thakur, V. Gupta, R.K., Matharu, A.S., Eilks, I. and Zuin, V.G. (eds.). (2018). Special issue: UN SGDs: how can sustainable chemistry contribute? / reuse and recycling / green chemistry in education. *Current Opinion in Green and Sustainable Chemistry* 13, A1-A10, 1-174. https://www.sciencedirect.com/journal/current-opinion-in-green-and-sustainable-chemistry/vol/13.

Yale University (n.d.). Global green chemistry initiative (GGCI). https://www.global-green-chemistry-initiative.com/. Accessed 2 May 2018.

Zuin, V.G. and Mammino, L. (eds.). (2015). *Worldwide Trends in Green Chemistry Education*. Cambridge, MA: Royal Society of Chemistry. https://doi.org/10.1039/9781782621942.

Zuin, V.G. (2016). Circularity in green chemical products, processes and services: innovative routes based on integrated eco-design and solution systems. *Current Opinion in Green and Sustainable Chemistry* 2, 40-44. http://doi.org/10.1016/j.cogsc.2016.09.008.

## Chapter 3

American Sustainable Business Council and Green Chemistry & Commerce Council (2015). *Making the Business & Economic Case for Safer Chemistry*. http://asbcouncil.org/sites/default/files/asbcsaferchemicalsreportpresred.pdf.

Baldwin, J.R., Gorecki, P., Caves, R.E., Dunne, T. and Haltiwanger, J. (1995). *The Dynamics of Industrial Competition: A North American Perspective*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511664700.

Bøllingtoft, A. and Ulhøi, J.P. (2005). The networked business incubator-leveraging entrepreneurial agency? *Journal of Business Venturing* 20(2), 265-290. https://doi.org/10.1016/j.jbusvent.2003.12.005.

Brigl, M., Roos, A., Schmieg, F. and Watten, D. (2014). *Incubators, Accelerators, Venturing, and More: How Leading Companies Search for Their Next Big Thing*. Boston, Ma: Boston Consulting Group. https://www.elkarbide.com/sites/default/files/incubators_accelerators_venturing_more_jun_2014_tcm80-163819.pdf.

Brigl, M., Hong, M., Roos, A., Schmieg, F. and Wu, X. (2016). Corporate venturing shifts gears. *Boston Consulting Group*, 25 April. https://www.bcg.com/en-ch/publications/2016/innovation-growth-corporate-venturing-shifts-gears-how-largest-companies-apply-tools-innovation.aspx. Accessed 18 February 2019.

Clark, B.R. (1998). *Creating Entrepreneurial Universities: Organizational Pathways of Transformation*. Issues in Higher Education. New York, NY: Pergamon Press. https://eric.ed.gov/?id=ED421938.

Coyle, P.E. (2011). *National Defense Industrial Association Science & Engineering Technology Division Executive Breakfast: The Missing Middle*. Washington, D.C.: United States Office of Science and Technology Policy. https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2011/SET/CoyleNDIA.pdf.

Dempwolf, C.S., Auer, J. and D'Ippolito, M. (2014). *Innovation Accelerators: Defining Characteristics Among Startup Assistance Organizations*. Washington, D.C.: United States Small Business Administration, Office of Advocacy. https://www.sba.gov/sites/default/files/rs425-Innovation-Accelerators-Report-FINAL.pdf.

Edmondson, G., Valigra, L., Kenward, M., Hudson, R.L. and Belfield, H. (2012). *Making Industry-University Partnerships Work. Lessons from Successful Collaborations.* Brussels: Science | Business Innovation Board. https://www.sciencebusiness.net/sites/default/files/archive/Assets/94fe6d15-5432-4cf9-a656-633248e63541.pdf.

Elgie, S. and Brownlee, M. (2017). *Accelerating Clean Innovation in Canada*. Ottawa: Smart Prosperity Institute. https://institute.smartprosperity.ca/sites/default/files/acceleratingcleaninnovationincanada.pdf.

Elschami, M. and Kümmerer, K. (2018). Sustainable Chemistry and the International Sustainable Chemistry Collaborative Centre. *GAIA – Ecological Perspectives for Science and Society* 27(2), 247-249. https://doi.org/10.14512/gaia.27.2.13.

Ernst & Young (2016). *Green Bonds: A Fresh Look at Financing Green Projects.* https://www.ey.com/Publication/vwLUAssets/Green_bonds-a-fresh-look-at-financing-green-projects/$FILE/EY-Green%20bonds-a-fresh-look-at-financing-green-projects.pdf.

Etzkowitz, H. (2002). *MIT and the Rise of Entrepreneurial Science*. Abingdon: Taylor & Francis. https://doi.org/10.4324/9780203216675.

Etzkowitz, H., Ranga, M., Benner, M., Guaranys, L., Maculan, A.M. and Kneller, R. (2008). Pathways to the entrepreneurial university: towards a global convergence. *Science and Public Policy* 35(9), 681-695. https://doi.org/10.3152/030234208x389701.

European Commission (2012). *Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions: 'A European Strategy for Key Enabling Technologies – A Bridge to Growth and Jobs'.* Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0341&from=EN.

European Commission and Organisation for Economic Co-operation and Development (2012). *A Guiding Framework for Entrepreneurial Universities*. https://www.oecd.org/site/cfecpr/EC-OECD%20Entrepreneurial%20Universities%20Framework.pdf.

Faulkner, A. and Berenshteyn, Y. (2013). *Advanced Materials: Creating Chemistry between Innovators and Investors.* San Francisco, CA: Cleantech Group. http://www.phoenix-vp.com/wp-content/uploads/2015/10/Advanced-Materials_Creating-Chemistry_0713.pdf.

Forrest, C. (2018). Accelerators vs. incubators: what startups need to know, 25 June. *TechRepublic*. https://www.techrepublic.com/article/accelerators-vs-incubators-what-startups-need-to-know/

Global Innovation through Science and Technology (2018). Startups. http://www.gistnetwork.org/content/startups. Accessed 18 February 2019.

Green Chemistry & Commerce Council (n.d. a). Members of the GC3 Startup Network. https://greenchemistryandcommerce.org/startup-network/list-of-startups. Accessed 18 February 2019.

Green Chemistry & Commerce Council (n.d. b). Advancing green chemistry across supply chains and Sectors. https://greenchemistryandcommerce.org/. Accessed 02 January 2019.

Hoffman, D.L. and Radojevich-Kelley, N. (2012). Analysis of accelerator companies: an exploratory case study of their programs, processes, and early results. *Small Business Institute® Journal* 8(2),54-70. https://www.sbij.org/index.php/SBIJ/article/view/136.

Huizingh, E.K.R.E. (2011). Open innovation: state of the art and future perspectives. *Technovation* 31(1), 2-9. https://doi.org/10.1016/j.technovation.2010.10.002.

IESE Business School (2017). *Corporate Venturing: Achieving Profitable Growth Through Startups. Whitepaper.* https://www.iese.edu/research/pdfs/ST-0429-E.pdf.

International Bank for Reconstruction and Development and World Bank (2017). *What Are Green Bonds?* http://documents.worldbank.org/curated/en/400251468187810398/pdf/99662-REVISED-WB-Green-Bond-Box393208B-PUBLIC.pdf.

International Council of Chemical Associations (2017). *Global Chemical Industry Contributions to the Sustainable Development Goals.* https://www.icca-chem.org/wp-content/uploads/2017/02/Global-Chemical-Industry-Contributions-to-the-UN-Sustainable-Development-Goals.pdf.

International Energy Agency (2008). *Energy Technology Perspectives 2008: Scenarios & Strategies to 2050*. https://www.iea.org/media/etp/etp2008.pdf.

Jackson, D.J. (2011). *What Is an Innovation Ecosystem?* Arlington, VA: National Science Foundation. http://www.sustainablescale.org/ConceptualFramework/UnderstandingScale/BasicConcepts/EcosystemFunctionsServices.aspx.

Kirchhoff, B.A., Newbert, S.L., Hasan, I., and Armington, C. (2007). The influence of university R&D expenditures on new business formations and employment growth. *Entrepreneurship Theory and Practice* 31(4),543-559. https://doi.org/10.1111/j.1540-6520.2007.00187.x.

Klofsten, M., and Jones-Evans, D. (2000). Comparing academic entrepreneurship in Europe – the case of Sweden and Ireland. *Small Business Economics* 14(4), 299-309. https://doi.org/10.1023/A:1008184601282.

Kutzhanova, N., Lyons, T.S. and Lichtenstein, G.A. (2009). Skill-based development of entrepreneurs and the role of personal and peer group coaching in enterprise development. *Economic Development Quarterly* 23(3), 193-210. https://doi.org/10.1177/0891242409336547.

Langenheim, J. (2018). Could seaweed solve Indonesia's plastic crisis? 27 June. *Guardian*. https://www.theguardian.com/environment/blog/2018/jun/27/could-seaweed-solve-indonesias-plastic-crisis. .

Lockett, N., Jack, S. and Larty, J. (2012). Motivations and challenges of network formation: entrepreneur and intermediary perspectives. *International Small Business Journal* 31(8), 866-889.https://doi.org/10.1177/0266242612448383.

Lopes Da Silva, C.E., Baptista Narcizo, R. and Cardoso, R. (2012). The proximity between academy, industry and government: towards a more sustainable development of a Brazilian oil region. Selection and/or peer review under responsibility of Institut Teknologi Bandung. *Procedia-Social and Behavioral Sciences* 52, 100-109. https://doi.org/10.1016/j.sbspro.2012.09.446.

Malairaja, C. and Zawdie, G. (2008). Science parks and university–industry collaboration in Malaysia. *Technology Analysis & Strategic Management* 20(6), 727-739. https://doi.org/10.1080/09537320802426432.

Mbaka, C. (2018). Gjenge Makers is providing alternative building materials and products made from recycled plastics, 27 February. *TechMoran*. https://techmoran.com/2018/02/27/gjenge-makers-providing-alternative-building-materials-products-made-recycled-plastics/. Accessed 25 February 2019.

Mirowski, P. and Sent, E.-M. (2007). The commercialization of science, and the response of STS. In *The Handbook of Science and Technology Studies*. Lynch, M. and Wajcman, J. (eds.). Cambfidge, MA: MIT Press. 635-689. https://philpapers.org/rec/MIRTCO-5.

National Aeronautics and Space Administration of the United States (2012). Technology readiness level, 28 October. https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html. Accessed 20 September 2018.

Organisation for Economic Co-operation and Development (1997). *National Innovation Systems*. https://www.oecd.org/science/inno/2101733.pdf.

Organisation for Economic Co-operation and Development (2011). *Invention and Transfer of Environmental Technologies*. OECD Studies on Environmental Innovation. http://dx.doi.org/10.1787/9789264115620-en.

Organisation for Economic Co-operation and Development (2012). *OECD Science, Technology and Industry Outlook 2012*. http://www.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-industry-outlook-2012_sti_outlook-2012-en.

Organisation for Economic Co-operation and Development (2016). *OECD Science, Technology and Innovation Outlook 2016*. https://doi.org/10.1787/sti_in_outlook-2016-en.

Oviatt, B.M., and Mc Dougall, P.P. (2005). Toward a theory of international new ventures. *Journal of International Business Studies* 36(1), 29-41. https://doi.org/10.1057/palgrave.jibs.8400128.

Root, A. (2017). *Scale Up! Entrepreneurs' Guide to Investment in Kenya*. Kariuki, M., Schwaab, J. and Wiedner, S. (eds.). Bonn: German Development Agency. https://make-it-initiative.org/africa/activities/guides-investment/.

Ryzhonkov, V. (2013). Innovation ecosystem model. *Entrepreneurship, Business Incubation, Business Models & Strategy Blog*. https://worldbusinessincubation.wordpress.com/2013/08/04/demand-not-the-infrastructure-is-the-cornerstone-of-successful-innovation-ecosystem/innovation-ecosystem-model-2/. Accessed 15 September 2018.

Schumpeter, J.A. (1954). *History of Economic Analysis*. Schumpeter. E.B. (ed.). New York: Oxford University Press. http://www.urbanlab.org/articles/economics/Schumpeter%201954%20-%20history%20economic%20analysis.pdf.

Sergey, A.B., Alexandr, D.B. and Sergey, A.T. (2015). Proof of Concept Center – a promising tool for innovative development at entrepreneurial universities. *Procedia – Social and Behavioral Sciences* 166, 240-245. https://doi.org/10.1016/j.sbspro.2014.12.518.

Şimşek, K. and Yıldırım, N. (2016). Constraints to open innovation in science and technology parks. *Procedia - Social and Behavioral Sciences* 235, 719-728. https://doi.org/10.1016/j.sbspro.2016.11.073.

Söderblom, A. and Samuelsson, M. (2014). *Sources of Capital for Innovative Startup Firms: An Empirical Study of the Swedish Situation.* Stockholm: Entreprenörskaps Forum. https://entreprenorskapsforum.se/wp-content/uploads/2014/05/NaPo_Sourcesofcapital_webb.pdf.

Storey, D.J. (1994). *Understanding the Small Business Sector*. London: Routledge. https://www.taylorfrancis.com/books/9781134838554.

SusChem (2017). *Strategic Innovation and Research Agenda*. http://www.suschem.org/publications.

Sworder, C., Salge, L. and van Soest, H. (2017). *Global Cleantech Innovation Index 2017: Which Countries Look Set to Produce the Next Generation of Start-Ups?* Cleantech Group and World Wide Fund for Nature. https://wwf.fi/mediabank/9906.pdf.

Sworder, C., Zhang, L. and Matheson, H. (2018). *Global'18 Cleantech 100: A Barometer of the Changing Face of Global Cleantech Innovation*. Steger, M. and Youngman, R. (eds.). Cleantech Group. http://info.cleantech.com/rs/151-JSY-946/images/2018Global100Report_weboptimized.pdf.

United Nations Economic Commission for Africa (2016a). *Enabling Measures for an Inclusive Green Economy in Africa*. http://www.greengrowthknowledge.org/sites/default/files/downloads/resource/UNECA_Enabling%20measures%20for%20an%20inclusive%20green%20economy%20in%20Africa.pdf.

United Nations Economic Commission for Africa (2016b). *Inclusive Green Economy Policies and Structural Transformation in Selected African Countries*. http://repository.uneca.org/bitstream/handle/10855/23004/b11560265.pdf?sequence=3.

United Nations Economic Commission for Europe (2012). *Innovation Review Performance Kazakhstan*. https://www.unece.org/fileadmin/DAM/ceci/publications/icp5.pdf.

United Nations Environment Programme (2017). *Advancing Entrepreneurship and Start-up Initiatives for Sustainable Chemistry: Learning from Case Studies. Compilation of Case Studies.* http://wedocs.unep.org/bitstream/handle/20.500.11822/22044/SC%20Startup%20WS_Case%20Studies%20Compilation_Final.pdf?sequence=1&isAllowed=y.

United Nations Industrial Development Organization (2017). *Industrial Development Report 2018. Demand for Manufacturing: Driving Inclusive and Sustainable Industrial Development*. https://www.unido.org/news/industrial-development-report-2018-launched.

United States Government Accountability Office (2018). *Chemical Innovation: Technologies to Make Processes and Products More Sustainable*. https://www.gao.gov/products/GAO-18-307.

Whitesides, G. (2015). Reinventing Chemistry. *Angewandte Chemie International Edition* 54(11), 3196-3209. https://doi.org/10.1002/anie.201410884.

Wilson, K.E. (2015). *Policy Lessons from Financing Innovative Firms*. OECD Science, Technology and Industry Policy Papers No. 24. Paris: Organisation for Economic Co-operation and Development. https://doi.org/10.1787/5js03z8zrh9p-en.

Wissema, J.G. (2009). *Towards the Third Generation University: Managing the University in Transition*. Cheltenham: Edward Elgar Publishing Limited. https://doi.org/10.4337/9781848446182.

World Economic Forum (2018). *Chemistry and Advanced Materials: Collaborative Innovation towards the Sustainable Development Goals*. Forthcoming. https://www.weforum.org/

Wu, J.J. and Atkinson, R.D. (2017). *How Technology-Based Start-Ups Support U.S. Economic Growth*. Information Technology & Innovation Foundation. http://www2.itif.org/2017-technology-based-start-ups.pdf.

Yuan and Powell (2013). *MOOCs and Open Education: Implications for Higher Education*. Bolton: Centre for Educational Technology, Interoperability and Standards. https://publications.cetis.org.uk/wp-content/uploads/2013/03/MOOCs-and-Open-Education.pdf.

## Chapter 4

Agarwal, D., Bersin, J., Lahiri, G., Schwartz, J. and Volini, E. (2018). *The Rise of the Social Enterprise: 2018 Deloitte Global Human Capital Trends*. Kaji, J., Edelman, K., Khan, A., Garia, N., Budman, M., Thomas, R. and Devan, P. (eds.). Deloitte. https://www2.deloitte.com/content/dam/insights/us/articles/HCTrends2018/2018-HCtrends_Rise-of-the-social-enterprise.pdf.

Agrawal, V.V. and Bellos, I. (2015). Servicizing in supply chains and environmental implications. In *Environmentally Responsible Supply Chains*. Atasu, A. (ed.). Cham: Springer. Chapter 7. 109-124. https://doi.org/10.1007/978-3-319-30094-8_7.

Alibaba (2018). Product listing policy, 10 May. http://rule.alibaba.com/rule/detail/2047.htm#p2.2. Accessed 16 September 2018.

Amazon (2018). Hazardous and dangerous items, 28 September. https://sellercentral.amazon.com/gp/help/external/200164570?language=en-US&ref=mpbc_200277300_cont_200164570. Accessed 22 February 2019.

American Institute of Chemical Engineers (2011). *Chemical Parks: Industry Landscaping à la Germany*. https://www.aiche.org/sites/default/files/cep/20111044.pdf.

Askar, Y. (2006). *Chemical Management Services: Advantages, Barriers and Opportunities in the Egyptian Market*. Lund: Lunds universitet Internationella miljöinstitutet. http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=1329423&fileOId=1329424.

Azimi, P., Zhao, D., Pouzet, C., Crain, N.E. and Stephens, B. (2016). Emissions of ultrafine particles and volatile organic compounds from commercially available desktop three-dimensional printers with multiple filaments. *Environmental Science & Technology* 50(3), 1260-1268. https://doi.org/10.1021/acs.est.5b04983

Beltramello, A., Haie-Fayle, L. and Pilat, D. (2013). *Why New Business Models Matter for Green Growth*. OECD Green Growth Papers. 2013-01. Paris: Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/content/paper/5k97gk40v3ln-en.

Bierma, T.J. and Waterstraat, F.L. (1997). *Innovative Chemical Supply Contracts: A Source of Competitive Advantage*. Champaign, IL: Waste Management and Research Center. https://www.ideals.illinois.edu/handle/2142/2042.

Bilsen, V., Blondiau, T., Debergh, P. and Lukach, R. (2013). *Exchange of Good Policy Practices Promoting Innovative/Green Business Models.* Brussels: European Commission Directorate-General Enterprise and Industry. http://ec.europa.eu/DocsRoom/documents/4668.

Bocken, N.M.P., Short, S.W., Rana, P. and Evans, S. (2014). A literature review to develop sustainable business model archetypes. *Journal of Cleaner Production* 65, 42-56. http://dx.doi.org/10.1016/j.jclepro.2013.11.039.

Chemical Leasing (2016). Joint declaration signed, 21 november 2016. https://chemicalleasing.org/news/joint-declaration-signed-21-november-2016. Accessed 22 February 2019.

Chemical Strategies Partnership (n.d. a) *Chemical Management Services: A New Strategy for Pollution Prevention.* https://www.dtsc.ca.gov/PollutionPrevention/upload/P2_FLY_Chemical_Management.pdf.

Chemical Strategies Partnership (n.d. b). *Chemical Strategies Partnership: A Supply-Chain Approach to Reducing Chemical Use*. http://www.chemicalstrategies.org/pdf/workshop_events/2008/JKJ_CMS101.pdf.

Chertow, M. and Park, J. (2016). Scholarship and practice in industrial symbiosis: 1989-2014. In *Taking Stock of Industrial Ecology*. Clift, R. and Druckman, A. (eds.). Cham: Springer. Chapter 5. 87-116. https://doi.org/10.1007/978-3-319-20571-7_5.

Clarity (2015). B2B eCommerce considerations for the chemical industry, 18 February. https://www.clarity-ventures.com/articles/b2b-ecommerce-considerations-for-the-chemical-industry. Accessed 17 September 2018.

Crawford, M. (2015). 3D printed drugs: what does the future hold? December. *American Society of Mechanical Engineers*. https://www.asme.org/engineering-topics/articles/manufacturing-design/3dprinted-drugs-does-future-hold. Accessed 14 August 2018.

Dambmann, D. and Allford, L. (2003). *A Walk in the Chemical Park – Process Safety Perspectives*. Institution of Chemical Engineers Symposium Series. No. 149. Manchester: Institution of Chemical Engineers. https://www.researchgate.net/publication/306255205_A_walk_in_the_chemical_park-_process_safety_perspectives.

Ding, L. (2017). How China's social enterprises can prosper alongside the country's state-run businesses, 27 June. *World Economic Forum*. https://www.weforum.org/agenda/2017/06/how-china-s-social-enterprises-can-prosper-alongside-the-country-s-state-run-businesses/. Accessed 14 August 2018.

Duffy, K. (2016). How 3D printing is driving the growth of small businesses, 17 May. https://www.manufacturing.net/article/2016/05/how-3d-printing-driving-growth-small-businesses. Accessed 18 September 2018.

Ebay (2018). Hazardous, restricted or regulated materials policy. https://www.ebay.com/help/policies/prohibited-restricted-items/hazardous-restricted-regulated-materials-policy?id=4335. Accessed 16 September 2018.

Erkman, S. and Van Hezik, C. (2016). *Global Assessment of Eco-Industrial Parks in Developing and Emerging Countries*. https://sofiesgroup.com/en/news/global-assessment-eco-industrial-parks-developing-emerging-countries/.

Ernst & Young (2013). *The Journey Toward Greater Customer Centricity*. https://www.ey.com/Publication/vwLUAssets/The_journey_toward_greater_customer_centricity/$FILE/Customer_Centricity_Paper_29_April_Final.pdf.

European Agency for Safety and Health at Work (2017). *3D Printing and Additive Manufacturing – the Implications for OSH*. https://osha.europa.eu/en/tools-and-publications/publications/3d-printing-new-industrial-revolution.

Evonik (2017). Evonik opens online flagship store on Alibaba, 7 November. https://corporate.evonik.com/en/media/search/pages/news-details.aspx?NewsId=70974. Accessed 22 August 2018.

Fairphone (2016). How we're tackling e-waste with the Fairphone 2, 25 February. https://www.fairphone.com/en/2016/02/25/tackling-e-waste-with-fairphone-2/. Accessed 15 September 2018.

Faludi, J. (2013). Is 3D printing an environmental win? 19 July. *GreenBiz*. https://www.greenbiz.com/blog/2013/07/19/3d-printing-environmental-win. Accessed 18 September 2018.

Faludi, J., Hu, Z., Alrashed, S., Braunholz, C., Kaul, S. and Kassaye, L. (2015). Does material choice drive sustainability of 3D printing? *International Journal of Mechanical and Mechatronics Engineering* 9(2), 216-223. http://scholar.waset.org/1307-6892/10000327.

Ford, S. and Despeisse, M. (2016). Additive manufacturing and sustainability: an exploratory study of the advantages and challenges. *Journal of Cleaner Production* 137, 1573-1587 https://doi.org/10.1016/j.jclepro.2016.04.150.

Gebler, M., Schoot Uiterkamp, A. and Visser, C. (2014). A global sustainability perspective on 3D printing technologies. *Energy Policy* 74, 158-167. https://doi.org/10.1016/j.enpol.2014.08.033.

Gładyszewski, K. and Skiborowski, M. (2018). Additive manufacturing of packings for rotating packed beds. *Chemical Engineering and Processing – Process Intensification* 127, 1-9. https://doi.org/10.1016/j.cep.2018.02.024.

Government of the United Kingdom (2016). Social investment tax relief: guidance, 23 November. https://www.gov.uk/government/publications/social-investment-tax-relief-factsheet/social-investment-tax-relief. Accessed 14 August 2018.

Guertzgen, S. (2017). How 3D printing will energize the chemical industry – Part 1: Key opportunity areas, 4 January. *Digitalist Magazine*. https://www.digitalistmag.com/digital-supply-networks/2017/01/04/3d-printing-energize-chemical-industry-part-1-04824179. Accessed 13 August 2018.

Hänsch Beuren, F., Gomez Ferreira, M.G. and Cauchick Miguel, P.A. (2013). Product-service systems: a literature review on integrated products and services. *Journal of Cleaner Production* 47, 222-231. https://doi.org/10.1016/j.jclepro.2012.12.028.

Hauthal, H. and Salonen, T. (n.d.) *Chemical Industrial Parks in China*. Achema World Wide News. https://dechema.de/dechema_media/Downloads/Presse/ACHEMA+worldwide/851_S_14_16-p-1146.pdf.

Ibrahim, A.M.S., Jose, R.R., Rabie, A.N., Gerstle, T.L., Lee, B.T. and Lin, S.J. (2015). Three-dimensional printing in developing countries. *Plastic and Reconstructive Surgery Global Open* 3(7), e443 1-8. https://doi.org/10.1097/gox.0000000000000298.

Independent Chemical Information Service Chemical Business (2018). Alibaba for chemicals as Covestro, BASF sign up, 26 April. https://www.icis.com/resources/news/2018/04/26/10215762/alibaba-for-chemicals-as-covestro-basf-sign-up/. Accessed 22 August 2018.

Independent Chemical Information Service News (2016). US Amazon now sells DVDs, books and caustic soda, 26 October. https://www.icis.com/resources/news/2016/10/26/10048495/us-amazon-now-sells-dvds-books-and-caustic-soda/. Accessed 22 August 2018.

Ishengoma, F.R. and Mtaho, A.B. (2014). 3D printing: developing countries perspectives. *International Journal of Computer Applications* 104(11), 30-34. https://www.researchgate.net/publication/267029274_3D_Printing_Developing_Countries_Perspectives.

Jakl, T. (2011). Global chemical leasing award 2010. *Technology and Investment* 2(1), 20-26. http://doi.org/10.4236/ti.2011.21003.

Jakl, T. and Schwager, P. (eds.) (2008). *Chemical Leasing Goes Global – Selling Services Instead of Barrels: A Win-Win Business Model for Environment and Industry*. Vienna: Springer Link. https://doi.org/10.1007/978-3-211-73752-1.

Joas, R. Abraham, V. and Joas, A. (2018). Chemical leasing: a business model to drive resource efficiency in the supply chain, In *Factor X*. Chapter 28. 395-403. https://doi.org/10.1007/978-3-319-50079-9_28

Kechichian, E. and Jeong, M.H (2016). *Mainstreaming Eco-Industrial Parks.* Washington, D.C.: World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/24921/Mainstreaming00020150event0in0Seoul.pdf?sequence=5&isAllowed=y.

Keizer, A., Stikkers, A., Heijmans, H., Carsouw, R. and Van Aanholt, W. (2016). *Scaling the Impact of the Social Enterprise Sector.* McKinsey & Company. https://www.social-enterprise.nl/files/9314/7809/5072/Scaling-the-impact-of-the-social-enterprise-sector.pdf.

Kreiger, M., Mulder, M., Glover, A. and Pearce, J. (2014). Life cycle analysis of distributed recycling of post-consumer high density polyethylene for 3-D printing filament. *Journal of Cleaner Production* 70, 90-96. https://doi.org/10.1016/j.jclepro.2014.02.009.

Kroner, E. (2014). The 7 pillars of customer centricity, 6 October. *American Marketing Association*. https://www.ama.org/publications/eNewsletters/MarketingInsightsNewsletter/Pages/7-pillars-of-customer-centricity.aspx. Accessed 13 August 2018.

LeBlanc, R., Tranchant, C., Gagnon, Y. and Côté, R. (2016). Potential for eco-industrial park development in Moncton, New Brunswick (Canada): a comparative analysis. *Sustainability* 8(5), 1-18. https://doi.org/10.3390/su8050472.

Ling, M. and Pflug, K. (2015). E-Business and chemical distribution: disintermediation 2.0? *China Chemical Reporter* 26(14), 8-9. http://www.mc-chemicals.com/sites/mc-chemicals.com/files/Ebusiness%20and%20Chemical%20Distribution%20CCR%202015.pdf.

March, R. (2015). 3D printing – exploring a technology and its sustainability potential, 21 December. http://sustainability.com/our-work/insights/3d-printing-exploring-a-technology-and-its-sustainability-potential/. Accessed 7 August 2018.

Mardani, S., Ojala, L.S., Uusi-Kyyny, P. and Alopaeus, V. (2016). Development of a unique modular distillation column using 3D printing. *Chemical Engineering and Processing: Process Intensification* 109, 136-148. https://doi.org/10.1016/j.cep.2016.09.001.

Market Research Engine (2017). Additive manufacturing market by end user analysis; by type analysis and by regional analysis – global forecast by 2016 – 2022, November. https://www.marketresearchengine.com/reportdetails/additive-manufacturing-market. Accessed 6 July 2018.

Mohammed, M.I., Mohan, M., Das, A., Johnson, M.D., Badwal, P.S., McLean, D. and Gibson, I. (2017). A low carbon footprint approach to the reconstitution of plastics into 3D- printer filament for enhanced waste reduction. *The International Conference on Design and Technology* 2017, 234-241. https://doi.org/10.18502/keg.v2i2.621.

Molitch-Hou, M. (2014). How a medical clinic in the Bolivian rainforest might use 3D printing, 18 February. https://3dprintingindustry.com/news/medical-clinic-bolivian-rainforest-might-use-3d-printing-23735/. Accessed 7 August 2018.

Moser, F. and Jakl, T. (2014). Chemical leasing – a review of implementation in the past decade. *Environmental Science and Pollution Research* 22, 6325-6348. https://doi.org/10.1007/s11356-014-3879-3.

Muhammed, A. (2018). Four challenges (millennial) social entrepreneurs should account for when running their businesses, 4 March. *Entrepreneurs*. https://www.entrepreneur.com/article/309905. Accessed 18 September 2018.

Okeugo, P. (2015). Wecyclers: Nigeria's sustainable waste recycling social enterprise, 22 September. http://www.nudgesustainabilityhub.com/initiatives/2015/9/21/wecyclers-nigerias-sustainable-waste-recycling-social-enterprise. Accessed 18 September 2018.

Organisation for Economic Co-operation and Development (2013). *Environmental Performance Review of Austria.* http://www.oecd.org/env/country-reviews/EPR%20Highlights%20AUSTRIA%202013%20web.pdf.

Organisation for Economic Co-operation and Development (2017). *Economic Features of Chemical Leasing.* Series on Risk Management. No. 37. https://www.oecd.org/chemicalsafety/risk-management/The%20Economic%20Features%20of%20Chemical%20Leasing.pdf.

Organisation for Economic Co-operation and Development and European Commission (2013). *Policy Brief on Social Entrepreneurship: Entrepreneurial Activities in Europe*. https://www.oecd.org/cfe/leed/Social%20entrepreneurship%20policy%20brief%20EN_FINAL.pdf.

Oskui, S.M., Diamante, G., Liao, C., Shi, W., Gan, J., Schlenk, D. and Grover, W.H. (2016). Assessing and reducing the toxicity of 3D-printed parts. *Environmental Science & Technology Letters* 3(1), 1-6. https://doi.org/10.1021/acs.estlett.5b00249.

Panum, K. and Hansen, M. (2014). *Successful Social Enterprises in Africa: Case Studies of Six Social Enterprises in Kenya*. CBDS Working Paper Series Working Paper No. 02. Copenhagen: Copenhagen Business School http://openarchive.cbs.dk/bitstream/handle/10398/9002/Panum_and_hansen_2014_2.pdf.

Perrini F. and Vurro C. (2006). Social entrepreneurship: innovation and social change across theory and practice. In *Social Entrepreneurship*. Mair, J., Robinson J. and Hockerts, K. (eds.). London: Palgrave Macmillan. Chapter 5. 57-85. https://doi.org/10.1057/9780230625655_5.

Phansey, A. (2014). How 3D printing can revolutionize sustainable design, 29 May. https://www.greenbiz.com/blog/2014/05/29/3d-printing-revolutionize-sustainable-design. Accessed 7 August 2018.

Planète Énergies (2016). Eco-industrial parks looking to enhance economic and environmental performance, 24 June. https://www.planete-energies.com/en/medias/close/eco-industrial-parks-looking-enhance-economic-and-environmental-performance. Accessed 19 September 2018.

Pullen, J.P. (2014). What 3D printing means for small business, 14 January. https://www.entrepreneurmag.co.za/advice/starting-a-business/launch/what-3d-printing-means-for-small-business/. Accessed 19 September 2018.

Ramus, T. and Vaccarus, A. (2017). Stakeholders matter: how social enterprises address mission drift. *Journal of Business Ethics* 143(2), 307-322. https://link.springer.com/article/10.1007/s10551-014-2353-y.

Renjen, P. (2018). Industry 4.0: are you ready? *Deloitte Review* (22), 9-11. https://www2.deloitte.com/content/dam/insights/us/collections/issue-22/DI_Deloitte-Review-22.pdf.

Roy, S. (2018). This startup has recycled over 4 tonnes of cigarette butts into useful products, 9 January. *YourStory Media*. https://yourstory.com/2018/01/code-enterprises/. Accessed 19 September 2018.

Sanchez, B. (2016). 10 policy tools that governments are implementing to spur social enterprise, 9 January. *World Bank*. http://blogs.worldbank.org/dmblog/10-policy-tools-governments-are-implementing-spur-social-enterprise. Accessed 9 August 2018.

Service, R. (2018). You could soon be manufacturing your own drugs—thanks to 3D printing, 18 January. *Science*. http://www.sciencemag.org/news/2018/01/you-could-soon-be-manufacturing-your-own-drugs-thanks-3d-printing. Accessed 22 February 2019.

Shockley, G.E. and Frank, P.M. (2011). The functions of government in social entrepreneurship: theory and preliminary evidence. *Regional Science Policy & Practice* 3(3), 181-198. https://doi.org/10.1111/j.1757-7802.2011.01036.x.

SIDBI Venture Capital (n.d.). Maharashtra state social venture fund (MS Fund). http://www.sidbiventure.co.in/ms_fund.html. Accessed 14 August 2018.

Smith, F. (2016). Trash to treasure: the social enterprises transforming recycling, 20 November. https://www.theguardian.com/sustainable-business/2016/nov/21/social-enterprises-transforming-recycling. Accessed 19 September 2018.

Social Enterprise Mark CIC (2018). The social enterprise mark – what it means. https://www.socialenterprisemark.org.uk/what-the-social-enterprise-mark-means/. Accessed 4 September 2018.

Solvay (2018). Alibaba! Solvay opens flagship e-store, 23 January. https://www.solvay.com/en/article/solvay-opens-alibaba-e-store. Accessed 22 August 2018.

Stringer, L. (2018). E-commerce: the challenges of enforcing a chemicals policy, June. *Chemical Watch*. https://chemicalwatch.com/67611/e-commerce-the-challenges-of-enforcing-a-chemicals-policy. Accessed 8 August 2018.

Technical Progress. (2018). Chemical Management Services (CMS) market 2018-2025: global industry report by product and region. https://thetechnicalprogress.com/2018/05/chemical-management-services-cms-market-2018-2025-global-industry-report-by-product-and-region/. Accessed 6 June 2018.

United Kingdom Chemicals Stakeholder Forum (2013). *A Guide to Chemical Services: An Information Note from the UK Chemicals Stakeholder Forum*. https://www.gov.uk/government/groups/uk-chemicals-stakeholder-forum.

United Nations Industrial Development Organization (2016). *Global Promotion and Implementation of Chemical Leasing Business Models in Industry*. http://www.recpnet.org/wp-content/uploads/2016/08/10-Years-Chemical-Leasing-Report.pdf.

United Nations Industrial Development Organization (2017). *Implementation Handbook for Eco-industrial Parks*. https://www.unido.org/sites/default/files/files/2018-05/UNIDO%20Eco-Industrial%20Park%20Handbook_English.pdf.

United Nations Industrial Development Organization (2019). Chemical leasing. https://www.unido.org/our-focus/safeguarding-environment/resource-efficient-and-low-carbon-industrial-production/chemical-leasing. Accessed 11 February 2019.

United Nations Industrial Development Organization, World Bank Group and German Corporation for International Cooperation (2017). *An International Framework for Eco-Industrial Parks*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/29110.

Villeneuve-Smith, F. and Temple, N. (2015). *State of Social Enterprise Survey 2015: Leading the World in Social Enterprise.* https://www.socialenterprise.org.uk/Handlers/Download.ashx?IDMF=828443a9-2f80-4c2a-ab2b-81befed6ed05.

Walker, C. (2017). Perpetual plastics – 3D printing with waste, 27 October. *Elsevier*. https://chemical-materials.elsevier.com/chemical-rd/perpetual-plastics-3d-printing-waste/. Accessed 13 August 2018.

Wayne, J. (2017). How 3D printing is empowering SMBs in manufacturing's digital transformation, 6 October. *Entrepreneur*. https://www.entrepreneur.com/article/300966. Accessed 13 August 2018.

World Bank (2018). Eco-industrial parks emerge as an effective approach to sustainable growth, 23 January. https://www.worldbank.org/en/news/feature/2018/01/23/eco-industrial-parks-emerge-as-an-effective-approach-to-sustainable-growth. Accessed 6 August 2018.

World Business Council for Sustainable Development (2018). *Chemical Sector SDG Roadmap*. https://www.wbcsd.org/Programs/People/Sustainable-Development-Goals/Resources/Chemical-Sector-SDG-Roadmap.

Yale School of Forestry & Environmental Studies (2017). Additive manufacturing and sustainability: the environmental implications of 3-D printing, 14 November. *ScienceDaily*. https://www.sciencedaily.com/releases/2017/11/171114142343.htm. Accessed 7 August 2018.

Yoon, D. (2018). Putting toxic chemicals on the map, 13 June. *International Chemical Secretariat*. http://chemsec.org/putting-toxic-chemicals-on-the-map/. Accessed 14 August 2018.

Yu, F., Han, F. and Cui, Z. (2015). Evolution of industrial symbiosis in an eco-industrial park in China. *Journal of Cleaner Production* 87, 339-347. https://doi.org/10.1016/j.jclepro.2014.10.058.

Zeng, G. and Bathelt, H. (2011). Divergent growth trajectories in China's chemical industry: the case of the newly developed industrial parks in Shanghai, Nanjing and Ningbo. *GeoJournal* 76(6), 675-698. https://doi.org/10.1007/s10708-009-9313-6.

Zhu, Q., Geng, Y., Sarkis, J. and Lai, K-H. (2014). Barriers to promoting eco industrial parks development in China. *Journal of Industrial Ecology* 19(3), 457-467. https://doi.org/10.1111/jiec.12176.

## Chapter 5

Böcker, T. and Finger, R. (2016). European pesticide tax schemes in comparison: an analysis of experiences and developments. *Sustainability* 8(4), 1-22. https://doi.org/10.3390/su8040378.

Canadian Association of Tire Recycling Agencies (2018). *Annual Report 2017.* https://www.catraonline.ca/storage/files/shares/publications-en/catra-annualreport-2017-final-feb-16-2018-english.pdf.

Convery, F., McDonnell, S. and Ferreira, S. (2007). The most popular tax in Europe? lessons from the Irish plastic bags levy. *Environmental and Resource Economics* 38(1), 1-11. https://doi.org/10.1007/s10640-006-9059-2.

Coria, J. (2018). The economics of toxic substance control and the REACH directive. *Review of Environmental Economics and Policy* 12(2), 342-358. http://dx.doi.org/10.1093/reep/rey003.

Dikgang, J., Leiman, A. and Visser, M. (2010). *Analysis of the Plastic-Bag Levy in South Africa*. Policy Paper. No. 18. https://econrsa.org/papers/p_papers/pp18.pdf.

Finger, R., Möhring, N., Dalhaus, T. And Böcker, T. (2017). Revisiting pesticide taxation schemes. *Ecological Economics* 134, 263-266. https://doi.org/10.1016/J.ECOLECON.2016.12.001.

Government of Denmark (2006). *Ftalater - Reguleringsmæssig Status, Ftalatafgiftens Effekter Og Overvejelser Om Differentieret Afgift (Phthalates - Regulatory Status, Effects of the Fee on Phthalates and Considerations about a Differentiated Charge)*. Miljø- og Planlægningsudvalget. Appendix 343. https://www.ft.dk/samling/20051/almdel/mpu/bilag/343/267804.pdf.

Groothuis, F. (2016). *New Era. New Plan: A Fiscal Strategy for an Inclusive, Circular Economy*. Gersen, P. (ed.). LX Houten: Ex'tax Project. http://www.neweranewplan.com/wp-content/uploads/2016/12/New-Era-New-Plan-Europe-Extax-Report-DEF.compressed.pdf.

Gu, Y.F., Wu, Y.F., Xu, M., Wang, H.D. and Zuo, T.Y. (2017). To realize better extended producer responsibility: redesign of WEEE fund mode in China. *Journal of Cleaner Production*, 164, 347-356. https://doi.org/10.1016/J.JCLEPRO.2017.06.168.

Gulati, A. and Banerjee, P. (2015). *Rationalising Fertiliser Subsidy in India: Key Issues and Policy Option*. Working Papers. No. 307. New Delhi: Indian Council for Research on International Economic Relations. https://ideas.repec.org/p/ess/wpaper/id11083.html.

Harrington, W., Morgenstern, R. and Sterner, T. (eds) (2004). *Choosing Environmental Policy: Comparing Instruments and Outcomes in the United States and Europe*. 1st edn. Washington, D.C.: Routledge. https://www.taylorfrancis.com/books/9781936331468.

Kalimo, H., Lifset, R., Atasu, A., Van Rossem, C. and Van Wassenhove, L. (2015). What roles for which stakeholders under extended producer responsibility? *Review of European Comparative & International Environmental Law* 24(1), 40-57. https://doi.org/10.1111/reel.12087.

Kjäll, K. (2012). *Hur väl Fungerar Miljöskatter Inom Kemikalieområdet? Effekter av Miljöskatter på Växtskydd och Klorerade Lösningsmedel i Sverige, Danmark, Norge och Frankrike*. Stockholm: Swedish Chemicals Agency.

Loblaw Companies Limited. (2017). *2017 Corporate Social Responsibility Report.* http://www.loblaw.ca/CSRReport.pdf.

Organisation for Economic Co-operation and Development. (n.d.). Database on policy instruments for the environment. https://pinedatabase.oecd.org/. Accessed 13 July 2018.

Ørum, J.E., Kudsk, P. and Jensen, P.K. (2017). Economics of site-specific and variable-dose herbicide application. In *Precision Agriculture: Technology and Economic Perspectives*. Springer, Cham. Chapter 4. 93-110. https://doi.org/10.1007/978-3-319-68715-5_4.

Praveen, K.V., Aditya, K.S, Nithyashree, M.L. and Sharma, A. (2017). Fertilizer subsidies in India: an insight to distribution and equity issues. *Journal of Crop and Weed* 13(3), 24-31. https://www.cabdirect.org/cabdirect/abstract/20183048688.

Slunge, D. and Sterner, T. (2001). Implementation of policy instruments for chlorinated solvents: a comparison of design standards, bans, and taxes to phase out trichloroethylene. *European Environment* 11(5), 281-296. https://doi.org/10.1002/eet.271.

Söderholm, P. (2009). *Economic Instruments in Chemicals Policy: Past Experiences and Prospects for Future Use*. Copenhagen: Copenhagen: Nordic Council of Ministers. https://www.elibrary.imf.org/abstract/IMF931/21827-9789289319201/21827-9789289319201/21827-9789289319201.xml?rskey=OZFzjS&result=8.

Söderholm, P. & Christiernsson, A. (2008). Policy effectiveness and acceptance in the taxation of environmentally damaging chemical compounds. *Environmental Science and Policy* 11(3), 240-252. Https://Doi.Org/10.1016/J.ENVSCI.2007.10.003.

Stavins, R.N. (2001). *Experience with Market-Based Environmental Policy Instruments*. Discussion Paper. No. 01-58. Washington, D.C.: Resources for the Future. https://ageconsearch.umn.edu/record/10909/files/dp010058.pdf.

Sterner, T. and Coria, J. (2011). *Policy Instruments for Environmental and Natural Resource Management*. 2nd edn. Washington, D.C.: Resources for the Future. https://doi.org/10.4324/9781315780894.

Stringer, L. (2017). Denmark to scrap tax on PVC and phthalates, 16 November. *Chemical Watch*. https://chemicalwatch.com/61121/denmark-to-scrap-tax-on-pvc-and-phthalates. Accessed 12 September 2018.

Turner, J.M. and Nugent, L.M. (2016). Charging up battery recycling policies extended producer responsibility for single-use batteries in the European Union, Canada, and the United States. *Journal of Industrial Ecology* 20(5), 1148-1158. https://doi.org/10.1111/jiec.12351.

United Kingdom Department for Environment, Food & Rural Affairs (2018). Single-use plastic carrier bags charge: data in England for 2016 to 2017, 27 September. https://www.gov.uk/government/publications/carrier-bag-charge-summary-of-data-in-england/single-use-plastic-carrier-bags-charge-data-in-england-for-2016-to-2017. Accessed 21 February 2018.

Vatn, A. (1998). Input versus emission taxes: environmental taxes in a mass balance and transaction costs perspective. *Land Economics* 74(4), 514. https://doi.org/10.2307/3146882.

Weitzman, M. L. (1974). Prices vs quantities. *The Review of Economic Studies* 41(4), 477-491. https://doi.org/10.2307/2296698.

Zeng, X. L., Duan, H. B., Wang, F. and Li, J. H. (2017). Examining environmental management of e-waste: China's experience and lessons. *Renewable & Sustainable Energy Reviews* 72, 1076-1082. https://doi.org/10.1016/J.RSER.2016.10.015.

## Chapter 6

amfori (2019). amfori BEPI Supply Chain Chemical Management Module (SCCM). https://www.amfori.org/content/bepi-supply-chain-chemical-management-module-sccm. Accessed 20 February 2019.

BASF (2015). Chemical initiative "together for sustainability" (TfS). https://www.basf.com/en/company/about-us/suppliers-and-partners/sustainability-in-procurement/together-for-sustainability.html. Accessed 9 September 2018.

Blome, C., Foerstl, K., Schleper, M.C., (2017). Antecedents of green supplier championing and greenwashing: An empirical study on leadership and ethical incentives. *Journal of Cleaner Production* 152, 339-350. https://doi.org/10.1016/j.jclepro.2017.03.052.

Bomgardner, M. (2016). Cleaning the clothing industry. *Chemical and Engineering News* 94(26), 30-32. https://cen.acs.org/articles/94/i26/Cleaning-clothing-industry.html

Boström, M., Jönsson, A.M., Lockie, S., Mol, A.P.J., Oosterveer, P., (2015). Sustainable and responsible supply chain governance: challenges and opportunities. *Journal of Cleaner Production* 107, 1-7. https://doi.org/10.1016/j.jclepro.2014.11.050.

Dora, M., Bhatia, M.S., Gallear, D. (2016). *Supply Chain in a Circular Economy: A Multidimensional Research Agenda*. 3rd International Conference on Green Supply Chain. London: Brunel University. https://bura.brunel.ac.uk/handle/2438/13002.

EcoVadis (2015). *Collaboration Drives Sustainability Efficiently, in the Chemical Industry Supply Chain.* https://www.ecovadis.com/library/together-sustainability-chemical-industry-supply-chain/#download.

EcoVadis (2017). Four beauty industry leaders and EcoVadis launch the Responsible Beauty Initiative, a shared vision to strengthen sustainability throughout the beauty supply chain, 14 November. https://www.ecovadis.com/four-beauty-industry-leaders-ecovadis-launch-responsible-beauty-initiative/. Accessed 14 September 2018.

Ernst & Young Global Limited (2016). *The State of Sustainable Supply Chains: Building Responsible and Resilient Supply Chains.* https://www.ey.com/Publication/vwLUAssets/EY-the-state-of-sustainable-supply-chains/$FILE/EY-building-responsible-and-resilient-supply-chains.pdf.

European Chemicals Agency (2018). New database on Candidate List substances in articles by 2021, 11 July. https://echa.europa.eu/-/new-database-on-candidate-list-substances-in-articles-by-2021. Accessed 30 December 2018.

European Commission (2015). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Closing the Loop - an EU Action Plan for the Circular Economy*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614.

European Commission (2018). *Communication from the Commission - On the Implementation of the Circular Economy Package: Options to Address the Interface Between Chemical, Product and Waste Legislation*. http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?doc_id=2733.

Fick, J., Söderström, H., Lindberg, R.H., Phan, C., Tysklind, M., Larsson, D.G.J., (2009). Contamination of surface, ground, and drinking water from pharmaceutical production. *Environmental Toxicology and Chemistry* 28, 2522-2527. https://doi.org/10.1897/09-073.1.

Foerstl, K., Reuter, C., Hartmann, E., Blome, C., (2010). Managing supplier sustainability risks in a dynamically changing environment - sustainable supplier management in the chemical industry. *Journal of Purchasing and Supply Management* 16(2), 118-130. https://doi.org/10.1016/j.pursup.2010.03.011.

Foerstl, K., Azadegan, A., Leppelt, T., Hartmann, E., (2015). Drivers of supplier sustainability: Moving beyond compliance to commitment. *Journal of Supply Chain Management* 51(1), 67-92. https://doi.org/10.1111/jscm.12067.

Forum for the Future (2018). Beauty and Personal Care Sustainability Project. https://www.forumforthefuture.org/bpc. Accessed 20 February 2018.

Friege, H., (2017). Sustainable Chemistry - a concept with important links to waste management. *Sustainable Chemistry and Pharmacy* 6, 57-60. https://doi.org/10.1016/j.scp.2017.08.001.

Genovese, A., Acquaye, A.A., Figueroa, A., Koh, S.C.L., (2017). Sustainable supply chain management and the transition towards a circular economy: evidence and some applications. *Omega* 66, 344-357. https://doi.org/10.1016/j.omega.2015.05.015.

Goldenman, G., Holland, M., Lietzmann, J. and Meura, L. (2017). *Study for the Strategy for a Non-Toxic Environment of the 7th Environment Action Programme: Final Report*. Brussels: European Commission DG Environment. https://doi.org/10.2779/025.

Goodnight, H., (2017). Blockchain: the best way to decentralize supply chains, 6 September. *Supply Chain Drive*. https://www.supplychaindive.com/news/blockchain-Sweetbridge-decentralization-supply-chain-management/504362/. Accessed 6 June 2018.

Ho, W., Zheng, T., Yildiz, H., Talluri, S. (2015). Supply chain risk management: a literature review. *International Journal of Production* Research 53(16), 5031-5069. https://doi.org/10.1080/00207543.2015.1030467.

Homrich, A.S., Galvão, G., Abadia, L.G., Carvalho, M.M., (2018). The circular economy umbrella: Trends and gaps on integrating pathways. *Journal of Cleaner Production* 175, 525-543. https://doi.org/10.1016/j.jclepro.2017.11.064.

International Business Machines Corporation (2018). *Blockchain Can Help Transform Supply Chain Networks in the Chemicals and Petroleum Industry: Blockchain Enables Immutable, Transparent and Auditable Business Transactions among Participants and Suppliers, Distributors and Partners.* https://www-01.ibm.com/common/ssi/cgi-bin/ssialias?htmlfid=CHJ12351USEN.

International Council of Chemical Associations (2015). Value chain outreach (VCO). https://www.icca-chem.org/value-chain-outreach-vco/. Accessed 14 September 2018.

Khan, O., Stolte, T., Creazza, A. and Hansen, Z. (2016). Integrating product design into the supply chain. *Cogent Engineering.* Zhou, Z. (ed.) 3(1), 1-24. https://doi.org/10.1080/23311916.2016.1210478.

Kingfisher (2018). *Chemicals Policy*. http://files.the-group.net/library/kgf/sustainability_policies/2017/pdfs/cr_10.pdf.

Kirchherr, J., Reike, D., Hekkert, M., (2017). Conceptualizing the circular economy: an analysis of 114 definitions. *Resources, Conservation and Recycling* 127, 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005.

Leppelt, T., Foerstl, K., Reuter, C., Hartmann, E., (2013). Sustainability management beyond organizational boundaries–sustainable supplier relationship management in the chemical industry. *Journal of Cleaner Production* 56, 94-102. https://doi.org/10.1016/j.jclepro.2011.10.011.

Lo, S. (2013). Effects of supply chain position on the motivation and practices of firms going green. *International Journal of Operations & Production Management* 34(1), 93-114. https://doi.org/10.1108/ijopm-04-2012-0133.

Marquis, C., Toffel, M. and Zhou, Y. (2016). Scrutiny, norms and selective disclosure: a global study of greenwashing. *Organization Science.* 27(2), 483-504. https://doi.org/10.1287/orsc.2015.1039

Metta, H. and Badurdeen, F. (2013). Integrating sustainable product and supply chain design: modeling issues and challenges. *IEEE Transactions on Engineering Management* 60(2), 438-446. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6336806.

Mezaros, S. (2017). *The Pharmaceutical Supply Chain Initiative: An Overview.* http://www.industrialgreenchem.com/pdf-docs/Vizag%20Conference%202017/Day%20I/The%20Pharmaceutical%20Supply%20Chain%20Initiative%20%E2%80%93%20An%20Overview%20by%20Steven%20Meszaros.pdf.

Patel, M. (2016). ICCA consults on value chain communication principles: safety information should be disclosed if 'based on science and risk', 15 December. *Chemical Watch*. https://chemicalwatch.com/51633/icca-consults-on-value-chain-communication-principles. Accessed 14 September 2018.

Perlmutter, A. (2015). *Advancing Safer Chemicals in Products: The Key Role of Purchasing.* Lowell Center for Sustainable Production, University of Massachusetts Lowell. https://www.epa.gov/sites/production/files/2015-09/documents/uml-rpt_greenpurchasing_7_15_14-2_0.pdf.

Porter, G. (2018). Apple, Target, Walmart get best grades in chemical policy review, 14 November. *Bloomberg* https://www.bloomberg.com/news/articles/2018-11-14/apple-target-walmart-get-best-grades-in-chemical-policy-review. Accessed 20 February 2019

Responsible Business Alliance (2018). *Responsible Business Alliance Code of Conduct Version 6.0.* http://www.responsiblebusiness.org/media/docs/RBACodeofConduct6.0_English.pdf

Retail Industry Leaders Association (n.d). *Chemicals and Toxics in Retail and its Supply Chain*. RILA Issue Brief: Chemicals and Toxics. http://www.retailcrc.org/sustainability/Lists/Briefings/Attachments/9/RILA%20issue%20brief%20-%20Chemicals%20and%20Toxics.pdf.

Rossi, M. (2014). *The Business Case for Knowing Chemicals in Products and Supply Chains.* http://web.unep.org/chemicalsandwaste/sites/unep.org.chemicalsandwaste/files/publications/UNEP CiP Business case_En.pdf.

Sager-Rosenthal, I. (2019). Major retailers phasing out worst of the worst chemicals: chemical laws help ensure safer products for all, 18 February. *Toxic-Free Future*. https://toxicfreefuture.org/major-retailers-phasing-out-worst-of-the-worst-chemicals/. Accessed 20 February 2019.

Scruggs, C. (2013). Reducing hazardous chemicals in consumer products: proactive company strategies. *Journal of Cleaner Production* 44, 105-114. https://doi.org/10.1016/j.jclepro.2012.12.005.

Sebastiani R., Corsaro D., Montagnini F. and Tzannis A. (2015). Sustainability in the supply chain: the retailers' perspective. In: *Marketing in Transition: Scarcity, Globalism, & Sustainability. Developments in Marketing Science: Proceedings of the Academy of Marketing Science.* Campbell C.L (ed.). 8-12. https://doi.org/10.1007/978-3-319-18687-0_5.

Sheldon, R.A., (2016). Green chemistry and resource efficiency: towards a green economy. *Green Chemistry* 18(11), 3180-3183. https://doi.org/10.1039/C6GC90040B.

Stringer, L. (2018). Cross-sector initiative sets full materials disclosure goal, 14 June. *Chemical Watch*. https://chemicalwatch.com/67695/cross-sector-initiative-sets-full-materials-disclosure-goal. Accessed 1 January 2019.

Sturcken, E. (2017). Walmart effect: Retailers lead the way on chemical safety at a critical time, 10 October. *Environmental Defense Fund*. https://www.edf.org/blog/2017/10/10/walmart-effect-retailers-lead-way-chemical-safety-critical-time. Accessed 9 September 2018.

Sustainable Brands (2017). Walmart's updated policy aims to drive toxic chemicals out of 90k household products, 28 September. https://www.sustainablebrands.com/news_and_views/chemistry_materials/sustainable_brands/walmarts_updated_policy_aims_drive_toxic_chemi. Accessed 14 September 2018.

Swedish Chemical Agency (2016). *Chemicals in Products: Challenges and Approaches.* https://www.kemi.se/global/broschyrer/chemicals-in-products.pdf.

Target (2017). Target announces new chemical strategy including policy and goals for its products and operations, 25 January. https://corporate.target.com/article/2017/01/chemical-policy-and-goals. Accessed 15 September 2018.

United Nations Environment Programme (2014). *Sustainability of Supply Chains and Sustainable Public Procurement: A Pre Study.* http://www.oneplanetnetwork.org/sites/default/files/sustainability_of_supply_chains_and_sustainable_public_procurement.pdf.

United Nations Environment Programme (2015). *The Chemicals in Products Programme: Guidance for Stakeholders on Exchanging Chemicals in Products Information*. http://www.saicm.org/Portals/12/Documents/EPI/Guidance%20for%20Stakeholder%20in%20Exchanging%20CiP%20Information_October2015.pdf.

United States Green Building Council (2019). Integrative Analysis of Building Materials. https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-healthca-87. Accessed 20 February 2019.

Van Hamelen, E. (2018). *Without Chemistry There Can Be No Circular Economy: The Imperative of a New Perspective on Chemicals and Materials Management.* Planegg: The Natural Step. https://thenaturalstep.org/wp-content/uploads/2018/05/20180508-_Circular-chemistry-EN-BioEDIT-TNSinternational.pdf.

Waerder, B., Stinnes, S. and Erdenberger, O. (2017). Design thinking as driver for innovation in the chemical industry. *Journal of Business Chemistry* 14(2), 41-50. http://www.businesschemistry.org/article/?article=247.

## Chapter 7

Ahi, P. and Searcy, C. (2015). An analysis of metrics used to measure performance in green and sustainable supply chains. *Journal of Cleaner Production* 86, 360–377. https://doi.org/10.1016/j.jclepro.2014.08.005.

Berrone, P. (2016). How to succeed at sustainability (and why greenwashing doesn't work), 25 September. *Forbes*. https://www.forbes.com/sites/iese/2016/09/15/how-to-succeed-at-sustainability-and-why-greenwashing-doesnt-work/#152316c3124e. Accessed 14 September 2018.

Blasco, J.L., King, A., McKenzie, M. and Karn, M. (2017). *The Road Ahead: The KPMG Survey of Corporate Responsibility Reporting 2017*. https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2017/10/kpmg-survey-of-corporate-responsibility-reporting-2017.pdf.

Bluesign (2018). Bluesign® system. http://www.bluesign.com. Accessed 14 September 2018.

Britzelmaier, B., Franziska, F., Landwehr, M. and Salerno, L. (2015). Evidences for sustainability in the chemical industry - An international comparison. *International Journal of Sales, Retailing and Marketing* 4(2), 3-21. http://www.ijsrm.com/ijsrm/Current_&_Past_Issues_files/IJSRM4-2.pdf.

Chemie3 (2018). Die initiative: Fortschrittsindikatoren von Chemie³ [Progress Indicators of Chemie³]. https://www.chemiehoch3.de/de/home/die-initiative/fortschrittsindikatoren.html. Accessed 14 September 2018.

Cleary, S. (2015). *Inquiry: Design of a Sustainable Financial System - Stock Exchanges and Sustainability.* Inquiry Working Paper. Geneva: United Nations Environment Programme. http://unepinquiry.org/wp-content/uploads/2015/12/Stock_Exchanges_and_Sustainability.pdf.

Cockcroft, L.-J. and Persich, T. (2017). *Insights on the Impact of REACH & CLP Implementation on Industry's Strategies in the Context of Sustainability: ECHA Corporate Sustainability Strategies - Final Report*. Risk & Policy Analysts Limited. https://echa.europa.eu/documents/10162/13637/echa_css_report_without_case_studies_en.pdf/a0a6f46f-16c8-fbea-8b41-9ff683aafe5c.

Cradle to Cradle Products Innovation Institute (2018). Product certification overview - get certified. https://www.c2ccertified.org/get-certified/product-certification. Accessed 14 September 2018.

Deloitte (2016). *Sustainability Disclosure*: *Getting Ahead* of the *Curve*. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/risk/us-risk-sustainability-disclosure.pdf.

Diamond, M.L., de Wit, C.A., Molander, S., Scheringer, M., Backhaus, T., Lohmann, R., Arvidsson, R., Bergman, Å., Hauschild, M., Holoubek, I., Persson, L., Suzuki, N., Vighi, M. and Zetzsch, C. (2015). Exploring the planetary boundary for chemical pollution. *Environment International* 78, 8-15. https://doi.org/10.1016/j.envint.2015.02.001.

Dow Chemical Company (2015). *2015 Sustainability Goals: The Sustainable Chemistry Index*. http://storage.dow.com.edgesuite.net/dow.com/sustainability/goals/50409-SustainableChemistry-WPaper-Digital.pdf.

Dow Chemical Company (2017). *2017 Dow Sustainability Report*. https://corporate.dow.com/-/media/dow/corporate/dow-corporate/sustainability/2025-goals/pdf/dow-2017-sustainability-report.ashx.

Eccles, R.G., Ioannou, I. and Serafeim, G. (2014). The impact of corporate sustainability on organizational processes and performance. *Management Science* 60(11), 2835–2857. https://doi.org/10.1287/mnsc.2014.1984.

Equator Principles (2013). *The Equator Principles: A Financial Industry Benchmark for Determining, Assessing and Managing Environmental and Social Risk in Projects*. http://equator-principles.com./wp-content/uploads/2017/03/equator_principles_III.pdf.

Financial Times (n.d.). Definition of ESG. *Lexicon*. http://lexicon.ft.com/Term?term=ESG. Accessed 15 August 2018

Fink, L. (2018). Larry Fink's letter to CEOs: a sense of purpose. *BlackRock*. https://www.blackrock.com/corporate/investor-relations/2018-larry-fink-ceo-letter. Accessed 14 September 2018.

Follette, C., Jung, U., Kharisov, I., zum Felde, A.M. and Rubel, H. (2017). Making a business case for sustainability in chemicals, 19 April. *The Boston Consulting Group*. https://www.bcg.com/publications/2017/making-business-case-sustainability-chemicals.aspx. Accessed 14 September 2018.

Future-Fit Foundation (2017). Business Benchmark. http://futurefitbusiness.org. Accessed 14 September 2018.

German Environment Agency (2011). *Guide on Sustainable Chemicals: A Decision Tool for Substance Manufacturers, Formulators and End Users of Chemicals*. https://www.umweltbundesamt.de/publikationen/guide-on-sustainable-chemicals.

German Environment Agency (2016). SubSelect - guide for the selection of sustainable chemicals, 15 November. https://www.umweltbundesamt.de/en/document/subselect-guide-for-the-selection-of-sustainable. Accessed 21 February 2019.

German Environment Agency (2018). Das instrument SMART 5 zur bewertung der nachhaltigkeit von chemikalienleasing [The instrument SMART 5 for the evaluation of the sustainability of chemical leasing]. https://www.umweltbundesamt.de/dokument/das-instrument-smart-5-zur-bewertung-der. Accessed 21 February 2019.

Global Reporting Initiative (2016). Sustainability disclosure database: SDG target 12.6 global real time tracker. http://database.globalreporting.org/SDG-12-6/Global-Tracker. Accessed 14 September 2018.

Global Reporting Initiative (n.d.). *Materiality: What Topics Should Organizations Include in Their Reports? Draft.* https://www.globalreporting.org/resourcelibrary/Materiality.pdf.

GoodGuide (2018). Let us guide you to what's good: search for healthier products. https://www.goodguide.com/#/. Accessed 14 September 2018.

Green Chemistry & Commerce Council (n.d. a). *S.C. Johnson Is Transforming Its Supply Chain to Create Products That Are Better for the Environment: Case Study for the Green Chemistry and Commerce Council (GC3)*. http://www.greenchemistryandcommerce.org/downloads/SCJ_final.pdf.

Green Chemistry & Commerce Council (n.d. b). Advancing green chemistry across sectors and supply chains. https://greenchemistryandcommerce.org/. Accessed 2 January 2019.

Haffar, M. and Searcy. C. (2018). The use of context-based environmental indicators in corporate reporting. *Journal of Cleaner Production* 192. 496-513. https://doi.org/10.1016/j.jclepro.2018.04.202.

International Chemical Secretariat (2017). Investor analysis of chemicals management increases thanks to ChemSec and RobecoSAM, 30 March. http://chemsec.org/investor-analysis-of-chemicals-management-increases-thanks-to-chemsec-and-robecosam/. Accessed 14 September 2018.

International Council of Chemical Associations (2015). *2015 Responsible Care Status Report*. https://www.icca-chem.org/wp-content/uploads/2015/09/2015-Responsible-Care-Status-Report.pdf.

International EPD System (2017). *Environmental Product Declarations*. https://www.environdec.com/News-archive/New-brochures-to-explain-EPDs-available/.

International Organization for Standardization (2019). Standards catalogue 13.020.50 – ecolabelling. https://www.iso.org/ics/13.020.50/x/. Accessed 1 January 2019.

KPMG, Global Reporting Initiative, United Nations Environment Programme and Center for Corporate Governance in Africa (2016). *Carrots & Sticks: Global trends in sustainability reporting regulation and policy*. https://www.carrotsandsticks.net/wp-content/uploads/2016/05/Carrots-Sticks-2016.pdf.

Kropp, R. (2014). Why companies need context-based sustainability metrics, 24 June. *GreenBiz*. https://www.greenbiz.com/blog/2014/06/26/context-based-sustainability-metrics. Accessed 14 September 2018.

McElroy, M.W. and Baue, B. (2013). Research needs and opportunities in context-based sustainability. *Financial Reporting* 2, 47-70. https://www.researchgate.net/publication/261653975_Research_Needs_and_Opportunities_in_Context-Based_Sustainability.

Principles for Responsible Investment (n.d.). PRI: ESG issues. https://www.unpri.org/esg-issues. Accessed 21 February 2019.

PUMA (2018). PUMA progress report 2017. https://about.puma.com/en/sustainability/environment/chemicals. Accessed 1 January 2019.

Ridoutt, B., Fantke, P., Pfister, S., Bare, J., Boulay, A.-M., Cherubini, F., Frischknecht, R., Hauschild, M., Hellweg, S., Henderson, A., Jolliet, O., Levasseur, A., Margni, M., McKone, T., Michelsen, O., Milà i Canals, L., Page, G., Pant, R., Raugei, M., Sala, S., Saouter, E., Verones, F. and Wiedmann, T. (2015). Making sense of the minefield of footprint indicators. *Environmental Science & Technology* 49(5), 2601-2603. https://doi.org/10.1021/acs.est.5b00163.

Robèrt, K.-H., Broman, G.I. and Basile, G. (2013). Analyzing the concept of planetary boundaries from a strategic sustainability perspective: how does humanity avoid tipping the planet? *Ecology and Society* 18(2), art5 1-9. https://doi.org/10.5751/es-05336-180205.

Rossi, M.S., Edwards, S., Peele, C. and Greiner, T. (2017). *The Chemical Footprint Project: 2017 Annual Report*. Chemical Footprint Project. https://www.chemicalfootprint.org/results/2017-report.

Rydberg, T., Sala, S., Bjorn, A., Molander, S., Payet, J., Posthuma, L., Sörme, L., Vighi, M. and Zijp, M.C. (2014). *Towards a Common Conceptual Framework for Chemical Footprint Bridging Risk Assessment and Life Cycle Assessment: Short Review and Way forward*. Extended Abstract and Oral Presentation at SETAC EU Annual Meeting. No. C 31. Göteborg: IVL Swedish Environmental Research Institute. https://www.ivl.se/download/18.4b1c947d15125e72dda13f6/1449742312935/C31.pdf.

S.C. Johnson & Son (2018). What's inside SC Johnson products. https://www.whatsinsidescjohnson.com/us/en. Accessed 14 September 2018.

Safer Chemicals, Healthy Families (2018a). Mind the store. https://saferchemicals.org/mind-the-store/. Accessed 14 September 2018.

Sigma-Aldrich (n.d.). Environmental Sustainability. https://www.sigmaaldrich.com/globalcitizenship/environmental.html. Accessed 14 September 2018.

Society of Environmental Toxicology and Chemistry (2018). About SETAC. https://www.setac.org/page/AboutSETAC. Accessed 21 February 2019.

Stacchezzini, R., Melloni, G and Lai, A. (2016). Sustainability management and reporting: the role of integrated reporting for communicating corporate sustainability management. *Journal of Cleaner Production* 136, 102-110. https://doi.org/10.1016/j.jclepro.2016.01.109.

Stec, S., Paszkiewicz, M. and Antypas, A. (2017). Is the time ripe for global binding norms for corporate accountability? *International Journal of Innovation and Sustainable Development* 11(2/3) 130-148. https://doi.org/10.1504/IJISD.2017.083321.

Sumitomo Chemical Group (2016). *CSR Report 2016: Sustainable Chemistry*. http://www.sumitomo-chem.co.jp/english/csr/report/docs/csr_report_e2016.pdf.

Sustainability Accounting Standards Board (2015). *Sustainability Accounting Standard Resource Transformation Sector: Chemicals - Sustainability Accounting Standard*. http://www.sasb.org/wp-content/uploads/2015/03/RT0101_Chemical_Standard2.pdf.

Sustainability Accounting Standards Board (2018). SASB materiality map™ https://materiality.sasb.org/?hsCtaTracking=28ae6e2d-2004-4a52-887f-819b72e9f70a%7C160e7227-a2ed-4f28-af33-dff50a769cf4. Accessed 14 September 2018.

Sustainalytics (n.d.). Sustainalytics. https://www.sustainalytics.com/. Accessed 14 September 2018.

Tickner, J.A. and Becker, M. (2016). Mainstreaming green chemistry: the need for metrics. *Current Opinion in Green and Sustainable Chemistry* 1, 1-4. https://doi.org/10.1016/j.cogsc.2016.07.002.

Together for Sustainability (2016). The chemical initiative for sustainable supply chains. https://tfs-initiative.com. Accessed 14 September 2018.

Tranchard, S. (2018). New version of ISO 14024 on ecolabelling just published, 9 March. *International Organization for Standardization*. https://www.iso.org/news/ref2273.html. Accessed 1 January 2019.

United Nations (2012). United Nations Conference on Sustainable Development, Rio+20. https://sustainabledevelopment.un.org/rio20. Accessed 11 September 2018.

United Nations (2018). Sustainable Development Goals Partnerships Platform: VinylPlus. https://sustainabledevelopment.un.org/partnership/?p=91. Accessed 21 February 2019.

United Nations Environment Programme (2017). Life Cycle Initiative. https://www.lifecycleinitiative.org/. Accessed 1 January 2019.

United Nations Environment Programme (2019). *Analysis of Stakeholder Submissions on Sustainable Chemistry Pursuant to UNEA Resolution 2/7*. http://www.saicm.org/Portals/12/Documents/meetings/OEWG3/inf/OEWG3-INF-22-Analysis.pdf.

United Nations Environment Programme and World Bank (2017). *Roadmap for a Sustainable Financial System*. Geneva and Washington, D.C.: United Nations Environment Programme and World Bank. http://documents.worldbank.org/curated/en/903601510548466486/pdf/121283-12-11-2017-15-33-33-RoadmapforaSustainableFinancialSystem.pdf.

United States Government Accountability Office (2018). *Chemical Innovation: Technologies to Make Processes and Products More Sustainable*. https://www.gao.gov/products/GAO-18-307.

United States Green Building Council (2018). LEED v4. https://new.usgbc.org/leed-v4. Accessed 14 September 2018.

World Business Council for Sustainable Development (2014). *Life Cycle Metrics for Chemical Products: A Guideline by the Chemical Sector to Assess and Report on the Environmental Footprint of Products, Based on Life Cycle Assessment*. https://www.wbcsd.org/Projects/Chemicals/Resources/Life-Cycle-Metrics-for-Chemical-Products.

World Business Council for Sustainable Development (2018). *Chemical Industry Methodology for Portfolio Sustainability Assessments (PSA)*. https://www.wbcsd.org/Programs/Energy-Circular-Economy/Factor-10/Sector-Deep-Dives/Resources/Chemical-Industry-Methodology-for-Portfolio-Sustainability-Assessments.

World Economic Forum (2019). Shaping the future of collaborative innovation in chemicals and materials. https://cn.weforum.org/projects/shaping-the-future-of-collaborative-innovation-in-chemicals-and-materials. Accessed 21 February 2019.

Zero Discharge of Hazardous Chemicals (2018). About ZDHC. https://www.roadmaptozero.com/about. Accessed 1 January 2019.

## Chapter 8

American Chemical Society Green Chemistry Institute (2017). DOZNTM – a quantitative green chemistry evaluator, 16 August. https://communities.acs.org/community/science/sustainability/green-chemistry-nexus-blog/blog/2017/08/16/dozn-a-quantitative-green-chemistry-evaluator. Accessed 16 July 2018.

American Family Life Assurance Company of Columbus and American Family Life Assurance Company of New York (2017). *2017 AFLAC CSR Survey: Storylines and Highlights*. https://www.aflac.com/docs/about-aflac/csr-survey-assets/2017-csr-survey-deck.pdf.

Antypas, A. and Paszkiewicz, M. (2015). Corporate social responsibility and corporate accountability: a historical overview. In *Corporate Responsibility and Sustainable Development: Exploring the Nexus of Private and Public Interests*. Rayman-Bacchus, L. and Walsh, P.R. (eds.). London: Routledge. Chapter 1. 29-48. https://www.taylorfrancis.com/books/e/9781317540991/chapters/10.4324%2F9781315727790-9.

BASF (2018). Our responsibility to respect human rights. https://www.basf.com/en/company/sustainability/employees-and-society/human-rights.html. Accessed 13 July 2018.

Biswas, A. and Roy, M. (2015). Green products: an exploratory study on the consumer behaviour in emerging economies of the east. *Journal of Cleaner Production* 87, 463-468. https://doi.org/10.1016/j.jclepro.2014.09.075.

Bonney, R., Phillips, T.B., Ballard, H.L. and Enck, J.W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science* 25(1), 2-16. https://doi.org/10.1177/0963662515607406.

Boston Consulting Group (2017). How innovation and collaboration can accelerate sustainability in fashion, 14 July. https://www.bcg.com/publications/2017/retail-how-innovation-collaboration-accelerate-sustainability-fashion.aspx. Accessed 24 July 2018.

Buerke, A., Straatmann, T., Lin-Hi, N. and Müller, K. (2017). Consumer awareness and sustainability-focused value orientation as motivating factors of responsible consumer behavior. *Review of Managerial Science* 11(4), 959-991. https://doi.org/10.1007/s11846-016-0211-2.

Business & Human Rights Resource Centre (2018). *Business & Human Rights in the Chemical Industry: An Assessment of Company Responses to Human Rights Issues*. https://www.business-humanrights.org/sites/default/files/BHRRC%20Chemical%20Briefing%2030%20Jan%202018.pdf.

California Office of Environmental Health Hazard Assessment (2013). Proposition 65 in plain language, 1 February. https://oehha.ca.gov/proposition-65/general-info/proposition-65-plain-language. Accessed 22 February 2019.

Canadian Centre for Occupational Health and Safety (2018). Employee rights, 29 June. https://www.ccohs.ca/youngworkers/resources/employeerights.html. Accessed 24 July 2018.

Carrington, D. (2018). Plastic microbeads ban enters force in UK, 9 January. *The Guardian*. https://www.theguardian.com/environment/2018/jan/09/plastic-microbeads-ban-enters-force-in-uk. Accessed 30 August 2018.

Caruana, R. and Chatzidakis, A. (2014). Consumer social responsibility (CnSR): toward a multi-level, multi-agent conceptualization of the "other CSR". *Journal of Business Ethics* 121(4), 577-592. https://doi.org/10.1007/s10551-013-1739-6.

Casson, L. (2017). Microbeads - we won! 21 July. *Greenpeace UK*. https://www.greenpeace.org.uk/microbeads-we-won/. Accessed 30 August 2018.

Chemical & Allied Industries' Association (2017). *Responsible Care® Performance Report 2017: South Africa*. https://www.caia.co.za/wp-content/uploads/2017/12/caia-responsible-care-report-2017-report.pdf.

Conick, H. (2018). How marketing banned microbeads, 28 February. *American Marketing Association*. https://www.ama.org/publications/MarketingNews/Pages/how-marketing-banned-microbeads.aspx. Accessed 24 July 2018.

Deloitte, Food Marketing Institute and Grocery Manufacturers Association (2016). *Capitalizing on the Shifting Consumer Food Value Equation*. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/consumer-business/us-fmi-gma-report.pdf.

Devadhasan, J.P., Kim, D., Lee, D.Y. and Kim, S. (2017). Smartphone coupled handheld array reader for real-time toxic gas detection. *Analytica Chimica Acta* 984, 168-176. https://doi.org/10.1016/j.aca.2017.06.036.

Drozdenko, R.G., Jensen, M. and Coelho, D. (2011). Pricing of green products: premiums paid, consumer characteristics and incentives. *International Journal of Business, Marketing, and Decision Sciences* 4(1), 106-116. https://www.researchgate.net/publication/267725435_Pricing_of_Green_Products_Premiums_Paid_Consumer_Characteristics_and_Incentives.

Eisenhardt, K. (2015). #80 – social media influences chemical industry to move beyond compliance, 12 February. *CERM® Risk Insights*. http://insights.cermacademy.com/2015/02/80-social-media-influences-chemical-industry-move-beyond-compliance-kelly-eisenhardt/. Accessed 16 September 2018.

Environmental Rights Database (n.d. a). Mexican national human rights commission's environmental actions. http://environmentalrightsdatabase.org/mexican-national-human-rights-commissions-environmental-actions/. Accessed 24 July 2018.

Environmental Rights Database (n.d. b). Jurisprudence of the Supreme Court of India relating to environmental protection. http://environmentalrightsdatabase.org/jurisprudence-of-the-supreme-court-of-india-relating-to-environmental-protection/. Accessed 16 September 2018.

Euro RSCG Worldwide (2011). New study shows millennials rejecting traditional politics in favor of individual action; heightened expectations of business, 11 March. *PR Newswire*. https://www.prnewswire.com/news-releases/new-study-shows-millennials-rejecting-traditional-politics-in-favor-of-individual-action-heightened-expectations-of-business-119756679.html. Accessed 24 July 2018.

European Agency for Safety and Health at Work (2018). Homepage. https://osha.europa.eu/en. Accessed 13 September 2018.

European Chemicals Agency (2018). How to participate in the public consultation on ECHA's draft recommendation. https://echa.europa.eu/participate-in-the-public-consultation. Accessed 29 August 2018.

GoodElectronics (2015). Challenge to the global electronics industry, 1 March. https://goodelectronics.org/challenge-to-the-global-electronics-industry/. Accessed 21 February 2019.

GoodGuide (2019). Personal care. https://www.goodguide.com/#/categories/152786. Accessed 21 February 2019.

Government of Canada (2016). Risk management of chemical substances: what is risk management? 4 July. https://www.canada.ca/en/health-canada/services/chemical-substances/canada-approach-chemicals/risk-management.html. Accessed 21 February 2019.

Government of Canada (2017). Risk assessment of chemical substances, 16 November. https://www.canada.ca/en/health-canada/services/chemical-substances/canada-approach-chemicals/risk-assessment.html. Accessed 21 February 2019.

Green America Center for Sustainability Solutions (n.d. a). About us. http://www.centerforsustainabilitysolutions.org/introduction#introduction-green-america. Accessed 21 February 2019.

Green America Center for Sustainability Solutions (n.d. b). *Cleaner Electronics Production Network*. https://static1.squarespace.com/static/558b1fe4e4b00725460da07a/t/5b43803888251beed8d49dd3/1531150394640/CEPN+Poster+for+Print.pdf.

Hancock, A. (2017). Younger consumers drive shift to ethical products, 23 December. *Financial Times*. https://www.ft.com/content/8b08bf4c-e5a0-11e7-8b99-0191e45377ec. Accessed 16 September 2018.

Hartmann, S. and Klaschka, U. (2017). Interested consumers' awareness of harmful chemicals in everyday products. *Environmental Sciences Europe* 29(1), 29. https://doi.org/10.1186/s12302-017-0127-8.

He, G., Boas, I., Mol, A.P.J. and Lu, Y. (2017). E-participation for environmental sustainability in transitional urban China. *Sustainability Science* 12(2), 187-202. https://doi.org/10.1007/s11625-016-0403-3.

Imam, J. (2015). Microbead ban signed by President Obama, 31 December. *CNN*. https://edition.cnn.com/2015/12/30/health/obama-bans-microbeads/index.html. Accessed 30 August 2018.

International Council of Chemical Associations (2015). Responsible care global charter. https://www.icca-chem.org/responsible-care-global-charter/. Accessed 16 September 2018.

International Food Information Council Foundation (2018). *2018 Food and Health Survey*. https://www.foodinsight.org/2018-food-and-health-survey.

International Network for Economic Social & Cultural Rights (2018). Lagos del Campo vs Peru, case no. 12.795, judgment of 31 August 2017 (preliminary objections, merits, reparations and costs), 26 April. https://www.escr-net.org/caselaw/2018/lagos-del-campo-vs-peru-case-no-12795-judgment-31-august-2017-preliminary-objections. Accessed 13 September 2018.

Inter-American Commission on Human Rights (2011). Article 13 - American Convention on human rights: freedom of thought and expression, 1 August. *Organization of American States*. http://www.oas.org/en/iachr/expression/showarticle.asp?artID=25&lID=1. Accessed 16 September 2018.

Joyce, K. and Senier, L. (2017). Why environmental exposures? *Environmental Sociology* 3(2), 101-106. https://doi.org/10.1080/23251042.2017.1281375.

Khare, A. (2015). Antecedents to green buying behaviour: a study on consumers in an emerging economy. *Marketing Intelligence & Planning* 33(3), 309-329. https://doi.org/10.1108/mip-05-2014-0083.

Klara, R. (2018). Switching to healthy ingredients is riskier for brands than you might think, 5 January. *Adweek*. https://www.adweek.com/brand-marketing/switching-to-healthy-ingredients-is-riskier-for-brands-than-you-might-think/. Accessed 16 September 2018.

Klaschka, U. (2016). Natural personal care products-analysis of ingredient lists and legal situation. *Environmental Sciences Europe* 28(8), 1-14. https://doi.org/10.1186/s12302-016-0076-7.

Klaschka, U. (2017). Where are the SVHCs? 10 years consumer's right to know' about substances of very high concern. *Environmental Sciences Europe* 29(24), 1-14. https://doi.org/10.1186/s12302-017-0122-0.

Kumar, P. and Ghodeswar, B.M. (2015). Factors affecting consumers' green product purchase decisions. *Marketing Intelligence & Planning* 33(3), 330-347. https://doi.org/10.1108/mip-03-2014-0068.

LIFE AskREACH (2018). Consumer app inquiry results in international company taking product off the market, 7 May. https://www.askreach.eu/consumer-app-inquiry-results-in-international-company-taking-product-off-the-market/. Accessed 30 August 2018.

Lovell, T. (2018). EU-wide app to learn from Danish project problems, 13 March. *Chemical Watch*. https://chemicalwatch.com/64821/eu-wide-app-to-learn-from-danish-project-problems. Accessed 30 August 2018.

Luca, F.-A., Ciobanu, C.-I., Andrei, A., Horodnic, A., Luca, F.-A., Ciobanu, C.-I., Andrei, A.G. and Horodnic, A. V. (2018). Raising awareness on health impact of the chemicals used in consumer products: Empirical evidence from East-central Europe. *Sustainability* 10(1), 209. https://doi.org/10.3390/su10010209.

Maniatis, P. (2016). Investigating factors influencing consumer decision-making while choosing green products. *Journal of Cleaner Production* 132, 215-228. https://doi.org/10.1016/j.jclepro.2015.02.067.

Mathios, A.D. (2000). The impact of mandatory disclosure laws on product choices: an analysis of the salad dressing market. *The Journal of Law and Economics* 43(2), 651-678. https://doi.org/10.1086/467468.

Merck (2017). Merck corporate responsibility report 2016: human rights, 28 April. http://reports.merckgroup.com/2016/cr-report/strategy-management/human-rights.html. Accessed 17 September 2018.

Mitchell, E.A.D., Mulhauser, B., Mulot, M., Mutabazi, A., Glauser, G. and Aebi, A. (2017). A worldwide survey of neonicotinoids in honey. *Science* 358(6359), 109-111. https://doi.org/10.1126/science.aan3684.

National Geographic and Globescan (2014). *Greendex 2014: A Consumer Choice and the Environment - A Worldwide Tracking Survey*. https://globescan.com/wp-content/uploads/2017/07/Greendex_2014_Full_Report_NationalGeographic_GlobeScan.pdf.

Nielsen (2016). *What's in Our Food and on Our Minds: Ingredient and Dining Out Trends Around the World*. https://www.nielsen.com/content/dam/nielsenglobal/eu/docs/pdf/Global%20Ingredient%20and%20Out-of-Home%20Dining%20Trends%20Report%20FINAL%20(1).pdf.

O'Rourke, D. and Ringer, A. (2016). The impact of sustainability information on consumer decision making. *Journal of Industrial Ecology* 20(4), 882-892. https://doi.org/10.1111/jiec.12310.

Office of the United Nations High Commissioner for Human Rights (2018). Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes. https://www.ohchr.org/en/issues/environment/toxicwastes/pages/srtoxicwastesindex.aspx. Accessed 13 September 2018.

Olson, E.L. (2013). It's not easy being green: the effects of attribute tradeoffs on green product preference and choice. *Journal of the Academy of Marketing Science* 41(2), 171-184. https://doi.org/10.1007/s11747-012-0305-6.

Organisation for Economic Co-operation and Development (2017). *Tackling Environmental Problems with the Help of Behavioural Insights*. http://dx.doi.org/10.1787/9789264273887-en.

Organisation for Economic Co-operation and Development (2018). Green growth and consumer behaviour. http://www.oecd.org/greengrowth/greengrowthandconsumerbehaviour.htm. Accessed 17 September 2018.

Pan-European Coalition of Environmental Citizens Organisations (2016). *People Power for the Planet: How the Aarhus Convention Enables Citizens' Voices to Be Heard*. Silina, M. and Wates, J. (eds.). Brussels: European Environmental Bureau. http://eeb.org/wp-admin/admin-ajax.php?juwpfisadmin=false&action=wpfd&task=file.download&wpfd_category_id=106&wpfd_file_id=1493&token=ad69a8ebd1b1324d26331563ee0e323e&preview=1.

Peters, B. (2018). Unpacking the diversity of procedural environmental rights: the European Convention on Human Rights and the Aarhus Convention. *Journal of Environmental Law* 30(1), 1-27. https://doi.org/10.1093/jel/eqx023.

Registro de Emisiones y Transferencias de Contaminantes (n.d.). Últimas noticias. http://www.retc.cl/. Accessed 17 September 2018.

Rochman, C.M., Kross, S.M., Armstrong, J.B., Bogan, M.T., Darling, E.S., Green, S.J., Smyth, A.R. and Veríssimo, D. (2015). Scientific evidence supports a ban on microbeads. *Environmental Science & Technology* 49(18), 10759-10761. https://doi.org/10.1021/acs.est.5b03909.

Sammons, C. (2016). 8 mobile apps to help you reduce your exposure to harmful chemicals (& find toxin free food, cosmetics & household products), 8 August. *TimetoCleanse*. https://www.timetocleanse.com/8-mobile-apps-help-reduce-exposure-harmful-chemicals-find-toxin-free-food-cosmetics-household-products/. Accessed 30 August 2018.

Sanders, M. (2017). *When Compliance Isn't Enough: Protecting Your Brand from Negative Public Perception*. Burlington, MA: Haley & Aldrich. http://www.haleyaldrich.com/Portals/0/Downloads/BrandActionReport.pdf?timestamp=1491325162433.

Santiago, K.M., Caban-Martinez, A.J., Baum, J., Pangborn, J., Dikici, E., Solle, N.S., Sterling, D.A., Moore, K., Grace, K., Daunert, S., Deo, S. and Kobetz, E.N. (2018). Passive monitoring of chemical exposures in south Florida firefighters using silicone wristbands. *Occupational and Environmental Medicine* 75(Suppl 2), A203. https://doi.org/10.1136/oemed-2018-icohabstracts.574.

Scherer, C., Emberger-Klein, A. and Menrad, K. (2017). Biogenic product alternatives for children: consumer preferences for a set of sand toys made of bio-based plastic. *Sustainable Production and Consumption* 10, 1-14. https://doi.org/10.1016/j.spc.2016.11.001.

Shewan, D. (2017). Ethical marketing: 5 examples of companies with a conscience, 21 December. *WordStream*. https://www.wordstream.com/blog/ws/2017/09/20/ethical-marketing. Accessed 17 September 2018.

Sigma-Aldrich (2018). Greener alternatives evaluation matrix. https://www.sigmaaldrich.com/chemistry/greener-alternatives/matrix-scoring.html. Accessed 20 July 2018.

Silverstein, M.J. and Sayre, K. (2009). *The Female Economy*. Harvard Business Review. Cambridge, MA: Harvard Business School. https://hbr.org/2009/09/the-female-economy.

Soma, K., Onwezen, M.C., Salverda, I.E. and van Dam, R.I. (2016). Roles of citizens in environmental governance in the information age - four theoretical perspectives. *Current Opinion in Environmental Sustainability* 18, 122-130. https://doi.org/10.1016/j.cosust.2015.12.009.

Tan, Y. (2014). Transparency without democracy: the unexpected effects of China's environmental disclosure policy. *Governance* 27(1), 37-62. https://doi.org/10.1111/gove.12018.

Theobald, E.J., Ettinger, A.K., Burgess, H.K., DeBey, L.B., Schmidt, N.R., Froehlich, H.E., Wagner, C., HilleRisLambers, J., Tewksbury, J., Harsch, M.A. and Parrish, J.K. (2015). Global change and local solutions: tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation* 181, 236-244. https://doi.org/10.1016/j.biocon.2014.10.021.

Unilever (2018). *Unilever's Supply Chain*. https://www.unilever.com/Images/unilever-supply-chain-overview--may-2018_tcm244-523172_1_en.pdf.

United Nations (2018a). *Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean*. https://repositorio.cepal.org/bitstream/handle/11362/43583/1/S1800428_en.pdf.

United Nations (2018b). United Nations and the rule of law: access to justice. https://www.un.org/ruleoflaw/thematic-areas/access-to-justice-and-rule-of-law-institutions/access-to-justice/. Accessed 29 August 2018.

United Nations Development Programme (2014). *Environmental Justice: Comparative Experiences in Legal Empowerment*. http://www.undp.org/content/dam/undp/library/Democratic%20Governance/Access%20to%20Justice%20and%20Rule%20of%20Law/Environmental-Justice-Comparative-Experiences.pdf.

United Nations Educational Scientific and Cultural Organization (2017). *Unpacking Sustainable Development Goal 4 Education 2030: Guide*. http://unesdoc.unesco.org/images/0024/002463/246300E.pdf.

United Nations Environment Programme (2015). *Putting Rio Principle 10 into Action: An Implementation Guide*. http://wedocs.unep.org/handle/20.500.11822/11201.

United Nations Environment Programme (2018). First environmental law clinic opens in Wuhan University, China, 12 July. https://www.unenvironment.org/news-and-stories/blogpost/first-environmental-law-clinic-opens-wuhan-university-china. Accessed 24 July 2018.

United Nations Human Rights Council (2015). *Report of the Special Rapporteur on the Implications for Human Rights of the Environmentally Sound Management and Disposal of Hazardous Substances and Wastes, Baskut Tuncak*. https://www.ohchr.org/EN/Issues/Environment/ToxicWastes/Pages/Righttoinformation.aspx. Accessed 14 November 2018.

United Nations Human Rights Council (2018). *Report of the Special Rapporteur on the Implications for Human Rights of the Environmentally Sound Management and Disposal of Hazardous Substances and Wastes*. http://www.srtoxics.org/wp-content/uploads/2018/09/2018-HRC-report-on-Workers-Rights-EN.pdf.

United Nations Industrial Development Organization (2017). *Industrial Development Report 2018. Demand for Manufacturing: Driving Inclusive and Sustainable Industrial Development*. https://www.unido.org/news/industrial-development-report-2018-launched.

United Nations Special Rapporteur on Human Rights and Toxics (2016a). Right to information on hazardous substances and wastes. http://www.srtoxics.org/issues-of-interest/right-to-information/. Accessed 29 August 2018.

United Nations Special Rapporteur on Human Rights and Toxics (2016b). Human rights implicated by toxic chemicals. http://www.srtoxics.org/your-rights/. Accessed 29 August 2018.

United States Environmental Protection Agency (2018). Public participation process for registration actions, 21 December. https://www.epa.gov/pesticide-registration/public-participation-process-registration-actions. Accessed 22 February 2019.

United States Environmental Protection Agency (2017). Chemical data access tool, 17 March. *Data Catalog*. https://catalog.data.gov/dataset/chemical-data-access-tool. Accessed 13 September 2018.

United States Food and Drug Administration (2017). FDA confirms elevated levels of belladonna in certain homeopathic teething products, 27 January. https://www.fda.gov/newsevents/newsroom/pressannouncements/ucm538684.htm. Accessed 30 August 2018.

United States Occupational Safety and Health Administration (2016). *Workers' Rights*. United States Department of Labor. https://www.osha.gov/Publications/osha3021.pdf.

Wiersma, Y., Parsons, J. and Lukyanenko, R. (2016). Data quality in citizen science – a research study. *Environmental Scientist* 74–78. https://www.researchgate.net/publication/311206140.

Wine, O., Hackett, C., Campbell, S., Cabrera-Rivera, O., Buka, I., Zaiane, O., DeVito, S.C. and Osornio-Vargas, A. (2014). Using pollutant release and transfer register data in human health research: a scoping review. *Environmental Reviews* 22(1), 51-65. https://doi.org/10.1139/er-2013-0036.

Youngquist, C.P., Goldberger, J.R., Doyle, J. and Jones, S.S. (2015). Public involvement in waste management research and decision-making: a case study. *Regional Science Policy & Practice* 7(3), 141-161. https://doi.org/10.1111/rsp3.12061.

Zero Discharge of Hazardous Chemicals (2014). *2014 Right-to Know Disclosure Methodology Research: Joint Roadmap Version 2 Milestone*. https://www.roadmaptozero.com/fileadmin/layout/media/downloads/en/RightToKnowDisclosureMethodologies.pdf.

Zero Discharge of Hazardous Chemicals (2018). Leading the textile, leather and footwear industries towards zero discharge of hazardous chemicals. https://www.roadmaptozero.com/. Accessed 2 August 2018.

Zettler, E.R., Takada, H., Monteleone, B., Mallos, N., Eriksen, M. and Amaral-Zettler, L.A. (2016). Incorporating citizen science to study plastics in the environment. *Analytical Methods* 9(9), 1392-1403. https://doi.org/10.1039/c6ay02716d.

# V. Scaling up collaborative action under the 2030 Agenda for Sustainable Development

## About Part V

Part V places the insights generated in Parts I-IV within the context of the 2030 Agenda for Sustainable Development, focusing on opportunities for collaborative action to achieve the sound management of chemicals and waste. Emphasis is put on collaborative action to integrate chemicals and waste considerations into key economic and enabling sectors. A forward-looking discussion follows with respect to securing commitments by key stakeholders relevant to the future framework on chemicals and waste beyond 2020. Part V concludes by presenting a range of options for implementation of actions (referred to as "actions") to reach relevant Sustainable Development Goals (SDGs) and targets up to and beyond 2020. The listed actions have been identified based on the findings presented in Parts I-IV of the GCO-II.

## Highlights

- The 2030 Agenda provides a renewed opportunity to integrate chemicals and waste considerations into national development planning and sectoral policies and programmes.
- A growing number of stakeholders are using the 2030 Agenda to document their chemicals and waste related actions, but further momentum is needed and questions arise how to measure results.
- Strengthening chemicals and waste management programmes at all levels is critical to achieve SGD Targets 12.4 and 3.9, which focus on chemicals and waste.
- A comprehensive global framework is needed, with ambitious priorities, coherent indicators, and incentives to foster commitment and engagement by all relevant actors.
- Ten action areas with specific options for the implementation of actions to reach relevant SDGs and targets, up to and beyond 2020, have been identified by the GCO-II.
- Country and stakeholder driven action plans and roadmaps to achieve the sound management of chemicals and waste could be the foundation for reviewing progress at the global level.

## Contents

1/ The 2030 Agenda for Sustainable Development: an integrated framework for action 630

2/ Strengthening collaborative action on chemicals and waste in line with the 2030 Agenda 641

3/ Engaging all sectors and actors in chemicals and waste management beyond 2020 651

References 655

# 1/ The 2030 Agenda for Sustainable Development: an integrated framework for action

## 1.1 Advancing chemicals and waste within the 2030 Agenda for Sustainable Development

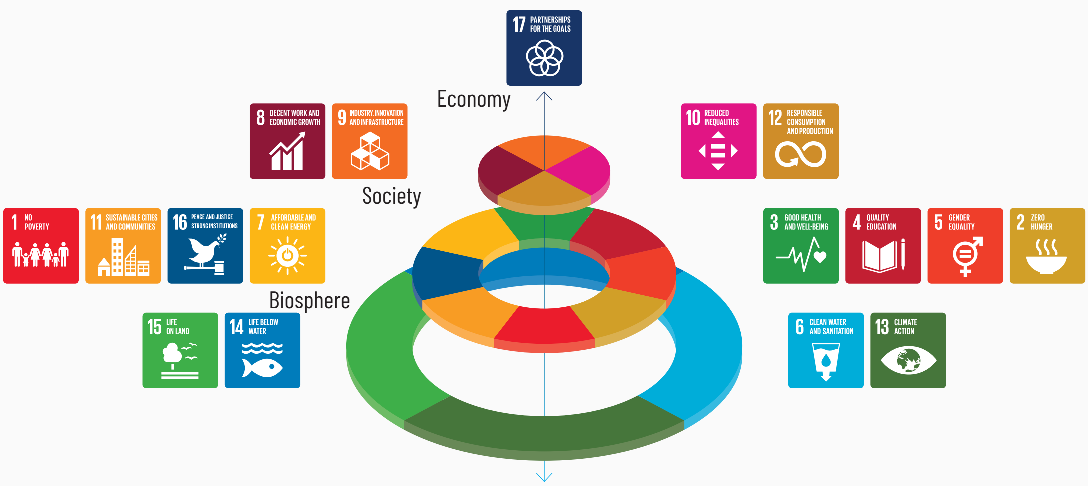
### The integrated nature of the Sustainable Development Goals (SDGs)

The 2030 Agenda emphasizes that development needs to be compatible with all three dimensions of sustainability: economic, social and environmental. Sustainable development is integrated and indivisible, meaning that it needs to be implemented as a whole rather than in a fragmented manner. Figure 1.1 illustrates the three dimensions of sustainable development as three interdependent systems, with the biosphere serving as a foundation for the development of societies and economies. A logic whereby social, economic and ecological development are distinct is replaced by a view in which the economy serves society within the safe operating space of the planet (Stockholm Resilience Centre [SRC] 2016).

### The SDGs are a robust framework for addressing chemicals and waste

The sound management of chemicals and waste cuts across the 17 SDGs. It is a crucial element underpinning the implementation of the 2030 Agenda, as chemicals and waste affect many aspects of development (Figure 1.2). This is reflected directly or indirectly in a number of goals and targets. While SDG Targets 12.4 and 3.9 are of direct relevance for a range of chemicals and waste management issues, SDG Target 6.3 focuses specifically on improving water quality. Equally relevant, a number of SDGs and targets are relevant for chemical-intensive sectors, for example those pertaining to access to food, clean energy and safe housing. These SDGs and targets cannot be achieved in a sustainable manner without due consideration of the sound management of chemicals and waste. Furthermore, chemicals and waste issues are relevant for a number of enabling SDGs and targets, including those concerned with access to information, education and financing.

**Figure 1.1** The three dimensions of sustainability (adapted from SRC 2016)



## The SDGs provide an opportunity to mainstream chemicals and waste management in policymaking

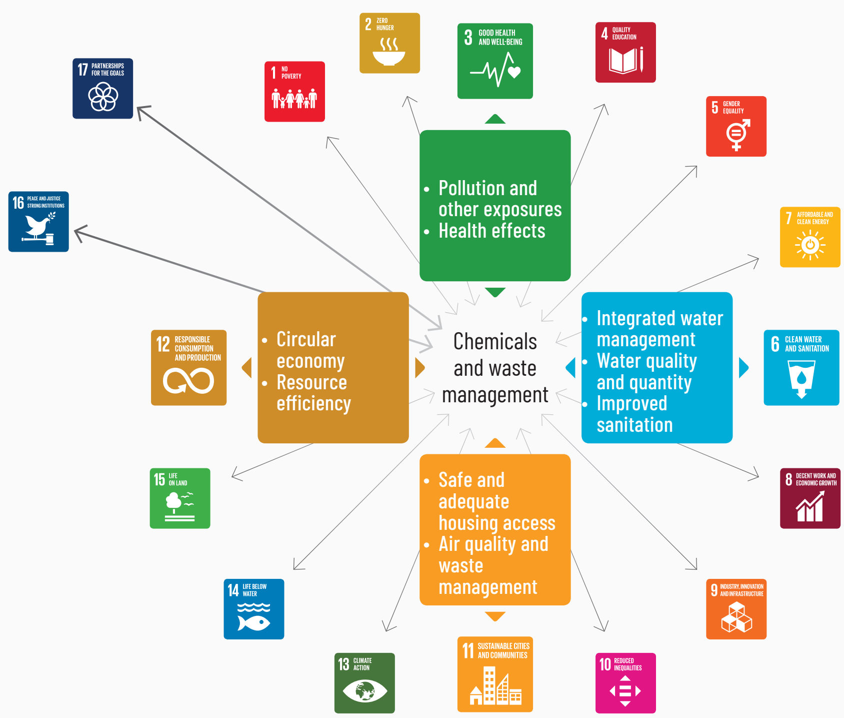
The significance of mainstreaming chemicals and waste considerations in national development policies, plans and sectoral policies for chemical-intensive economic sectors has been recognized by, among others, the Dubai Declaration and the Overarching Policy Strategy adopted in 2006. It is also addressed in the Overall Orientation and Guidance adopted by Strategic Approach to International Chemicals Management (SAICM) stakeholders in 2015. Despite these calls for action, gaps remain in achieving that ambition.

The 2030 Agenda creates new opportunities to integrate sound chemicals and waste management in national development policies and plans, as well as in sectoral policies and actions. Linkages exist, for example, with ending poverty (SDG 1); promoting sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all (SDG 8); and building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation (SDG 9). The 2030 Agenda also creates opportunities to include chemicals and waste management considerations in national and sub-national budgeting, and in the allocation of national financial resources, in line with the integrated approach to financing across its three components (mainstreaming, industry involvement, and dedicated external financing). Equally important is the integration of chemicals and waste management considerations in international development assistance and capacity building programmes (SDG Targets 17.6 and 17.8).

## SDG 17: A call for new partnerships and an opportunity for collaborative action

The 2030 Agenda is built on the premise that sustainable development can only be achieved by bringing together all countries and stakeholders. Given the diversity of the challenges related to chemicals and waste and the resources needed, protecting human health and the environment from the adverse effects of chemicals and waste, and maximizing the contributions of chemistry to sustainable development, require collaborative

**Figure 1.2** Linkages between chemicals and waste and the SDGs (adapted from Inter-Organization Programme for the Sound Management of Chemicals [IOMC] 2018, p. 3)



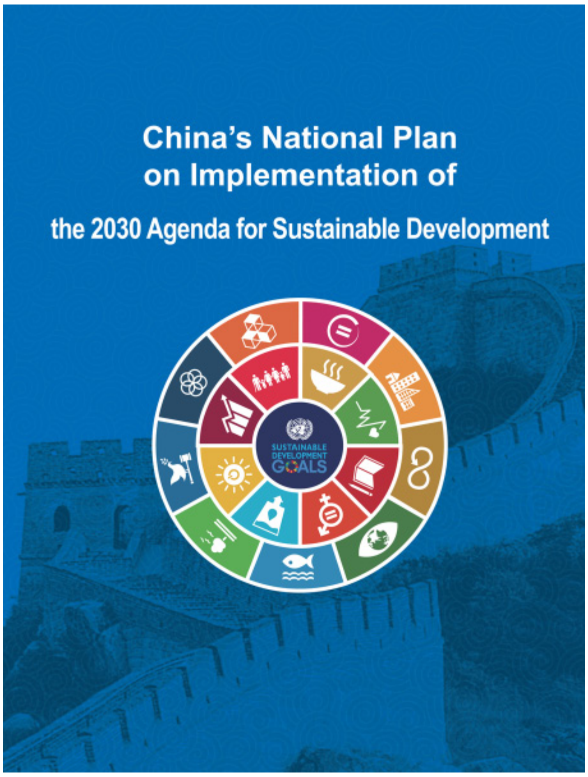

© IISD/ENB | Kiara Worth, High Level Political Forum Recap: The world's report card on global goals (iisd.org/library/hlpf-recap)

action to advance the sound management of chemicals and waste, bringing together all relevant stakeholders across sectors and with a common vision. Providing a global vision that brings together all countries and all stakeholders, the 2030 Agenda thus presents an opportunity for collaborative action at all levels to achieve a sustainable future with and through chemicals.

Sustainable Development Goal 17 calls on the global community to strengthen the means to implement and revitalize the global partnership for sustainable development. The complexity and magnitude of the SDGs can only be adequately addressed through the coordinated efforts of multiple stakeholders working in close collaboration (World Economic Forum 2018). Partnerships and collaborative action are equally critical in addressing chemicals and waste issues. They can provide an enabling environment that cuts across sectors. An expanded and results-based global collaborative framework for the sound management of chemicals and waste would therefore be a critical step forward with respect to addressing legacies and advancing innovative solutions. Therefore, the period up to the conclusion of the intersessional process to prepare recommendations regarding the Strategic Approach and the sound management of chemicals and waste beyond 2020 provides a brief but critical window in which to develop an ambitious and comprehensive global framework – as well as to increase engagement by all stakeholders.

## 1.2 Chemicals and waste stakeholders are starting to use the SDG framework

The 2030 Agenda has been widely endorsed. It has also started to inspire stakeholders, including in the area of sound management of chemicals and waste. Although initiatives are still at an early stage, some stakeholders engaged in the sound management of chemicals (including governments, the private sector, civil society,




academia and intergovernmental organizations) are undertaking activities to use the 2030 Agenda as an organizing framework and as a framework to communicate how their initiatives and actions contribute to achieving relevant SDGs and targets.

### Initial government actions to link chemicals and waste to the 2030 Agenda

Governments have begun to link sound management of chemicals and waste with the broader sustainable development context. For example, China's National Plan on Implementation of the 2030 Agenda maps action plans against the targets, noting, among others, under Target 3.9 the establishment of a monitoring system and, under Target 12.4, improving the level of green chemical industry technologies (Government of China 2016). In their Voluntary National Reviews for the High Level Political Forum, some governments have indicated how actions related to the sound management of chemicals and waste help achieve progress towards meeting various SDGs and targets. Thailand, for example, recognizes chemicals and waste in its review as a cross-cutting issue relevant to achieving, among others, SDGs 3, 11 and 12 (Government of Thailand 2017).

In the context of an exercise to outline how the EU contributes to the implementation of the 2030 Agenda, mapping has been prepared to show how various EU policies and actions support the implementation of SDG Target 12.4. Nigeria has compiled data concerning national progress on indicator 12.4.1 (hazardous waste generated per capita) as part of a broader exercise to establish a baseline for the SDG indicators (Government of the Federal Republic of Nigeria 2017). It is also making efforts to monitor progress at the sub-national level (Kaduna State Government 2017). In Denmark, statistical information is presented on a dedicated website, where national information related to the indicators under Target 12.4 is compiled (Statistics Denmark 2018). Canada has compiled data related to indicator 3.9.3 and is transmitting information required by relevant international agreements, as measured by indicator 12.4.1 (Government of Canada 2018)

### Early signs of private sector use of the SDG framework


Several companies and industry associations are using the 2030 Agenda as a framework to communicate corporate policies concerned with advancing sound chemicals and waste management (United Nations Global Compact and Accenture Strategy 2016). Within the framework of the World Business Council for Sustainable Development (WBCSD), for example, chemical companies and industry associations from a number of countries have developed a roadmap exploring how the chemical sector can contribute to achieving various SDGs and targets (WBCSD 2017). In the context of the ChemistryCAN initiative, the European Chemical Industry Council (Cefic) has reiterated its commitment to the 2030 Agenda, describing the SDGs as a guiding framework for industry.

Companies and associations including BASF (2018), Cefic (2016), Dow (2018), Sumitomo (2018) and the International Council of Chemical Associations (2017) are establishing how they can contribute to meeting the SDGs (Figure 1.3). On its webpage, CropLife International explores linkages between the sustainable use and effective management of pesticides

**Figure 1.3** **Alignment of the Dow 2025 Sustainability Goals with the SDGs (Dow 2018, p. 41)**

| The SDGs | Leading the blueprint | Delivering breakthrough innovations | Advancing in circular economy | Valuing nature | Safe materials for a sustainable planet | Engaging impact communities, employees, customers | World-leading operations performance |
|---|---|---|---|---|---|---|---|
| 1 | | ● | | | ● | ● | |
| 2 | | ● | | | ● | | |
| 3 | | ● | | ● | ● | | ● |
| 4 | ● | | | | | ● | |
| 5 | ● | | | | | ● | |
| 6 | ● | ● | | | | | ● |
| 7 | | ● | | | | | ● |
| 8 | ● | | | | | ● | |
| 9 | ● | ● | ● | | | | |
| 10 | ● | ● | | ● | | ● | |
| 11 | ● | ● | | | ● | | |
| 12 | ● | ● | | | ● | | |
| 13 | ● | ● | | | | | ● |
| 14 | ● | | ● | ● | | | ● |
| 15 | ● | | ● | ● | | | ● |
| 16 | | | | | | ● | |
| 17 | ● | | | | | | |

and the SDGs (CropLife International 2019). VinylPlus, the European polyvinyl chloride (PVC) industry's voluntary commitment to sustainable development, reports annually on a set of sustainability goals and targets and is communicating on how these align with and contribute to the SDGs (VinylPlus 2018). Chemical-intensive downstream industries, such as textile production (Textile Exchange 2018), are also communicating on the linkages of their corporate strategies with the 2030 Agenda and making efforts to identify opportunities to contribute to the SDGs.

### Civil society stakeholders are using the SDGs to guide their actions

Non-governmental organizations (NGOs) are starting to use the SDGs as a framework to guide actions on chemicals and waste. For example, in a joint report the International POPs Elimination Network (IPEN) and the Pesticide Action Network (PAN) describe how actions related to chemical safety and toxic chemicals are relevant to many if not all of the SDGs (IPEN and PAN 2017). Another example is provided by WWF-Worldwide Fund for Nature, which has outlined business opportunities inherent in the 2030 Agenda, thereby highlighting how sound management of chemicals and waste can help achieve various SDGs and targets including agricultural productivity, food safety, air and water quality, and protection of ecosystems (Ugarte *et al.* 2017). Other NGOs have explored agroecology's potential to support the implementation of some SDGs and targets (Farrelly 2016).


### Use of the 2030 Agenda by academia and the research community to advance chemistry

A number of articles published in scientific journals have explored the role of the chemical industry and of green/sustainable chemistry in achieving the SDGs (Matlin *et al.* 2015; Axon and James 2018; Hitce *et al.* 2018). Chemists for Sustainability was formed as an international group to explore the role of chemistry in implementing the 2030 Agenda (International Organization for Chemical Sciences in Development 2018). Moreover, chemists and

**Box 1.1 Planetary boundaries, chemicals and waste, and the 2030 Agenda: a research perspective**

In the research sector the concept of "planetary boundaries", originally introduced by Rockström *et al.* (2009) and extended by Steffen *et al.* (2015), has been further developed to link with the implementation of the 2030 Agenda and its provision that each government set national targets guided by the global level of ambition (Hoff and Lobos Alva 2017). The concept already includes boundaries on biogeochemical flows (phosphorus and nitrogen), stratospheric ozone depletion and ocean acidification, which are all relevant to chemicals and waste management. A new boundary on "novel entities", which has not yet been quantified, includes synthetic chemicals as well as naturally occurring elements mobilized by anthropogenic activities, such as heavy metals (Steffen *et al.* 2015).

other scientists are gathering to exchange ideas on the role of chemistry in the context of the 2030 Agenda. The 4th Green and Sustainable Chemistry Conference in Dresden, Germany, in May 2019 will specifically discuss the role of chemistry in achieving the SDGs (Elsevier 2018).

## Intergovernmental organizations are mapping their actions against the SDGs

Intergovernmental organizations active in the area of chemicals and waste are looking at how their activities can contribute to achieving

**Table 1.1** **Indicative mapping of IOMC participating organizations' activities on the SDGs for sound chemicals and waste management (updated based on IOMC 2017)**

| SDG/IOMC participating organization | FAO | ILO | UNDP | UNEP | UNIDO | UNITAR | WHO | WB | OECD |
|---|---|---|---|---|---|---|---|---|---|
| No Poverty | L | A | A | A | | | | A | |
| Zero Hunger | L | | | A | | | | | A |
| Good Health & Well-being | A | A | L | A | A | A | L | | L |
| Quality Education | A | | | | | | | A | |
| Gender Equality | L | | A | | A | A | A | A | |
| Clean Water and Sanitation | A | A | | A | | A | L | A | L |
| Affordable and Clean Energy | A | A | A | A | A | | A | A | |
| Decent Work and Economic Growth | A | L | | A | A | A | A | A | |
| Industry, Innovation, and Infrastructure | | | A | A | L | A | | A | |
| Reduced Inequalities | A | | | | | | | A | |
| Sustainable Cities and Communities | A | A | L | A | A | A | A | | A |
| Responsible Consumption and Production | L | A | L | L | A | A | L | | L |
| Climate Action | A | A | L | | A | A | A | A | |
| Life Below Water | A | A | L | A | A | | | | |
| Life on Land | A | A | L | A | | A | | | |
| Peace, Justice, and Strong Institutions | | A | | | | | | | |
| Partnership for the Goals | A | | A | A | A | A | | A | |

The table provides an indicative mapping of IOMC participating organizations' activities on various SDGs. Organizations with a lead role with respect to chemicals and waste management related activities for a given goal are marked with a L. Organizations that contribute to or have some activities related to chemicals and waste management aspects within a given goal are marked with an A.

the SDGs. For example, the IOMC participating organizations have assessed the relevance of their policies and actions in regard to the 2030 Agenda and set out plans for future actions to implement the SDGs and targets (Table 1.1). A similar effort has been undertaken by the Secretariat of the Basel, Rotterdam and Stockholm Conventions (Secretariat of the Strategic Approach to International Chemicals Management [SAICM Secretariat] 2018).

## 1.3 Challenges in using the 2030 Agenda as a framework for action

While many stakeholders have embraced the 2030 Agenda, questions and challenges remain regarding its full implementation:

- *Is there a common understanding of sustainability*? Currently agreement is lacking on how to measure or assess the sustainability of chemical processes and products (United States Government Accountability Office 2018). This lack may make it difficult to assess, compare and monitor progress in a coherent manner. A related question is how far the existing indicators under relevant SDG targets (notably Targets 3.9 and 12.4) provide a solid basis for measuring relevant stakeholders' progress in a meaningful manner. Measuring the contributions of chemicals and waste related activities to other SDGs and targets may require additional indicators.

- *Are the three dimensions of sustainability adequately considered and approached holistically*? Given interactions between the SDGs and targets, the need to acknowledge both synergies and trade-offs, in order to reduce negative interactions while maximizing win-win situations, has been highlighted (Barbier and Burgess 2017; Morton, Pencheon and Squires 2017; Pradhan *et al.* 2017; Allen, Metternicht and Wiedmann 2018; Singh *et al.* 2018; Verles and Vellacott 2018). Inadequate consideration of, and reporting on, trade-offs may hamper credibility.

- *Do corporate reporting efforts around the SDGs provide a sufficient level of detail*? For example, a 2017 report by the WBCSD (WBCSD and Radley Yeldar 2017) found that while 79 per cent of the sustainability reports of the companies surveyed acknowledged the SDGs in some way, only 6 per cent aligned their strategies and targets with specific target-level SDG criteria and measured their contributions to achieving key SDGs.

- *Is the 2030 Agenda used as more than a communication tool*? Some stakeholders have raised concerns that communication efforts may remain generic and difficult to quantify, focusing instead on selected stories (Verles and Vellacott 2018). The term "SDG-washing" has been introduced to draw attention to the potential use of the SDGs as a marketing tool (Machingura and Lally 2017; Nieuwenkamp 2017; Verles and Vellacott 2018).

- *Is the 2030 Agenda stimulating and driving change beyond what might otherwise have occurred*? Many companies adopting the SDGs tend to be setting sustainability goals and targets already. The possibility exists that efforts to align with the SDGs could simply be a "rebranding" of already committed efforts.

- *Are a sufficient number of stakeholders using the 2030 Agenda as a framework for action*? Despite significant progress, and initiatives undertaken in various sectors, many stakeholders have not yet aligned their strategies and reporting with the SDGs and targets.

- *To what extent are efforts to use the 2030 Agenda part of multi-stakeholder collaboration*? Multi-stakeholder collaboration could help move action beyond communication efforts and strengthen accountability. By facilitating a transparent exchange on prioritization, it could ensure that due consideration is given to the three dimensions of sustainability.

## 1.4 Achieving progress through effective collaborative action

### Towards collaborative action under the 2030 Agenda

Bringing together stakeholders representing different sectors and societal interests relevant to chemicals and waste is in line with the integrated policy nature of the 2030 Agenda and its spirit of collaboration and equity. Such a framework could provide a space, incentives and rewards to bring together relevant sectors and stakeholders, including vulnerable and marginalized groups. In establishing such a framework, stakeholders could draw on the experience of other existing initiatives and international instruments, such as the Strategic Plan for Biodiversity 2011-2020, the 2015 Paris Agreement on climate change, and the 2017 Marrakech Partnership for Global Climate Action.

### Lessons from effective multi-stakeholder collaboration

Multi-stakeholder collaboration is a challenging endeavour. Different forms of collaborative action on sustainability objectives differ in their specific considerations and scope. Yet a number of experiences and lessons learned emerge from such initiatives, including elements that make approaches effective. One model that has been proposed to help partnerships achieve their full potential highlights the importance of putting in place essential "building blocks" for a more collaborative society (Figure 1.4). This model highlights success factors (e.g. the policy context and the supporting infrastructure for partnerships); the design of partnerships; the maturity, or readiness to partner, of organizations; and the skills and competencies of individuals involved in the collaboration.

Numerous theories and frameworks exist that seek to support sustainable innovations, and to scale them up through collaboration to achieve change around a commonly identified objective. In reviewing these models, some common elements for successful multi-stakeholder collaboration emerge:

- *People*: respecting the different viewpoints and skill sets of individuals and groups, and recognizing that a diversity of perspectives can give insights on the challenge and strengthen the outcomes.
- *Perspective*: establishing a common awareness of the challenge, the need for collaboration and the shared value, i.e. what is to be gained from working together.

**Figure 1.4 Building blocks for a collaborative society (based on Stibbe 2018)**

- *Purpose*: defining a collective purpose or vision, with aligned objectives for collaboration, taking into account the mutual benefits of collaboration as well as the individual interests of each actor.
- *Process*: establishing a transparent process that provides structure for different parties to engage, measure results, and scale up innovations together.
- *Partnering*: building the capacity of individuals to communicate and collaborate openly, and providing leadership to convene and facilitate collaboration.
- Practice: recognizing that establishing new ways of working together takes time and requires a commitment to learning and experimentation in order to break new ground.

A recent study (Kuruvilla *et al.* 2018) explored means to ensure that multisectoral collaboration is effective, efficient, and contributes to transformative change in the context of sustainable development. Based on a review of a number of country case studies, success factors for multisectoral collaboration were identified (Figure 1.5).

**Figure 1.5** **A multisectoral collaboration model to achieve transformative change (adapted from Kuruvilla *et al*. 2018, p. 3)**


Adapted with permission from BMJ Publishing Group Limited

Based on multi-case study research. focusing on sustainable development and health issues, Kuruvilla *et al.* (2018) identified enabling factors that make "multi-sectoral collaboration work" in order to achieve transformational change. These insights could be of relevance in (re-)designing future collaborative action on chemicals and waste at all levels.

Based on multi-case study research, focusing on sustainable development and health issues, Kuruvilla *et al.* (2018) identified enabling factors that make "multi-sectoral collaboration work" in order to achieve transformational change. These insights could be of relevance in (re-)designing future collaborative action on chemicals and waste at all levels.

### Challenges and opportunities for collaborative action on chemicals and waste

Lessons on multi-stakeholder collaboration are especially relevant for addressing chemicals and waste issues, as they cut across all societal and economic sectors. Collaboration on chemicals also involves a number of unique considerations, such as addressing chemicals' complexity and measuring their effects; the historical context of chemical pollution; public perceptions of chemicals; and the differing views of experts and generalists on chemicals' sustainability potential. These and other factors can negatively influence, or at least complicate, efforts to achieve multi-stakeholder collaboration. The 2030 Agenda provides a new opportunity for a collaborative and integrated approach to chemicals and waste by allowing the topic to be viewed in the context of the broader objective of achieving sustainable development.

# 2/ Strengthening collaborative action on chemicals and waste in line with the 2030 Agenda

The 2030 Agenda provides a range of opportunities for scaling up collaborative action to achieve the sound management of chemicals and waste. These opportunities include collaborative action to achieve SDG Targets 12.4 and 3.9, focusing on chemicals and waste, which can be considered main drivers for developing and implementing effective and integrated chemicals and waste management programmes. They also include collaborative actions to implement the chemicals and waste dimension of SDG targets related to economic sectors (such as agriculture or housing) as well as to enabling sectors (such as education or financing). Finally, they include the development of a comprehensive global framework featuring ambitious priorities and coherent indicators.

## 2.1 Strengthening chemicals and waste management programmes at all levels

SDG Targets 12.4 and 3.9 are at the core of the sound management of chemicals and waste. They are the drivers for developing and implementing effective and integrated systems and programmes for the sound management of chemicals and waste covering all stages of the life cycle. Opportunities therefore exist for all stakeholders, working in a collaborative manner, to strengthen national and international chemicals and waste management actions and programmes and so contribute to the achievement of these and other related SDG targets.

### Establishing and strengthening national systems for sound management of chemicals and waste

The development of basic legislation and institutional capacity, in line with the Overall Orientation and Guidance and its 11 basic elements, has been recognized under the Strategic Approach to International Chemicals Management (SAICM) as critical at the national and regional levels to the attainment of sound chemicals and waste management. Many countries have already made important headway in enacting laws, creating programmes, and implementing policies to achieve the sound management of chemicals and waste. Valuable work has also been carried out by countries through the development of national chemicals management profiles and plans.

However, many other countries still lack effective national systems, including basic regulatory capacity and effective institutional structure. Such uneven progress puts vulnerable and marginalized groups at particular risk. Further steps to strengthen national systems for the sound management of chemicals and waste, particularly in developing countries and economies in transition, could include the following:

- Intensify action at all levels to strengthen legislative and institutional capacities.
- Strengthen country-driven processes via national chemicals management profiles and action plans on the sound management of chemicals and waste.

- Advance policy learning, alignment and harmonization across countries and maximize opportunities for regional cooperation, drawing on existing institutional structures.

### Filling data gaps and sharing knowledge globally

Although a wealth of data and knowledge has been generated, many data gaps and unknowns remain. These include gaps in regard to: chemical hazard data for a range of chemicals on the market; environmental, health and safety data; outdoor and indoor chemical releases; exposures and concentrations in humans and the environment; and adverse impacts of chemicals. Disparities remain in data collection and availability across time and countries, making the identification of baselines, trends, and emerging issues and priorities challenging. While a diverse set of mechanisms has been established at the international level to identify emerging issues and to set priorities for action, opportunities exist to explore the complementarity of processes and the use of science-based criteria for prioritization.

Various barriers pose challenges to making policy-relevant knowledge available for informed decision-making. Opportunities to strengthen the engagement of scientists and the science-policy interface include the following:

- Take steps towards the cost-effective harmonization of data generation and collection, strengthen monitoring and surveillance capacities, and share data more systematically at all levels.

- Scale up industry engagement in generating and disseminating relevant data.

- Strengthen two-way communication, and support collaboration between scientists and policymakers.

- Explore methodologies that facilitate more systematic identification of future priorities at the international level.

### Enhancing the effectiveness and use of chemicals management tools and approaches

For many years governments, intergovernmental organizations, industry and other stakeholders have been developing and employing a range of science-based approaches, tools, methodologies and instruments to advance sound chemicals management and implement the 2020 goal. These approaches, and the related generation of new information, serve to identify chemical hazards, assess the exposures and risks of chemicals, promulgate risk management decisions and actions when necessary, and assess alternatives. Collectively, they have contributed significantly to protecting human health and the environment.

At the same time, concerns have been expressed that current approaches are at times complex and slow and do not result in the progress needed. Over the past decades, valuable lessons have been learned in the practical application of these approaches, and opportunities have emerged to enhance their effectiveness, streamline their use, and employ them more systematically in all countries. Developing countries and economies in transition, in particular, stand to benefit from progress in these areas. Opportunities include the following:

- Accelerate chemical hazard assessment and harmonized classifications of substances.

- Refine chemical risk assessment and risk management decision-making process.

- Advance alternative assessments and informed substitution of chemicals of concern, including through non-chemical alternatives.

## 2.2 Mainstreaming chemicals and waste management into sector policies and actions

In addition to action to meet the SDG targets that directly address chemicals and waste management (SDG 12.4 and 3.9), the 2030 Agenda provides a renewed opportunity to strengthen inter-ministerial coordination mechanisms, and to integrate chemicals and waste considerations into relevant sector policies and actions. Environment and Health Ministries in a number of countries have successfully reached out to sectoral Ministries and established inter-agency/ inter-ministerial committees. Progress has thus been made in advancing chemicals and waste considerations in some sectors (e.g. in agriculture through the International Code of Conduct on Pesticide Management, and in health through the World Health Organization (WHO) Chemicals Road Map), while other sectors (e.g. housing) have so far received limited international attention.

### 2.2.1 Integrating chemicals and waste management into economic sectors

Chemical-intensive industry sectors, such as agriculture, construction, textiles, automobiles and electronics, are expanding globally, creating potential risks and opportunities. Mainstreaming sound management of chemicals and waste into these sectors can help ensure that economic growth and industrial development are sustainable and contribute to implementing the 2030 Agenda. However, many countries lack economic sector strategies and policies which ensure the sound management of chemicals and waste dimension.

Steps to integrate the sound management of chemicals and waste in economic sector policies and actions could include the following:

- Establish and strengthen inter-ministerial coordination mechanisms and processes for regular dialogues with key sectoral stakeholders at the national level.
- Take action to systematically integrate chemicals and waste management actions in sectoral policy frameworks.

Examples of opportunities to integrate chemicals and waste management, as well as green and sustainable chemistry innovation, in relevant economic sectors are shown in Table 2.1). In order to integrate chemicals and waste in economic sector policies and actions, concerned Ministries, working closely with respective policy communities, may consider initiating a structured

**Box 2.1 The WHO Chemicals Road Map**


On 30 May 2017, the Seventieth World Health Assembly approved the *Road map to enhance health sector engagement in the strategic approach to international chemicals management towards the 2020 goal and beyond* (the WHO Chemicals Road Map), as requested by Resolution WHA69.4.

The Road Map identifies actions where the health sector has either a lead or important supporting role to play, recognizing the need for multi-sectoral and multi-stakeholder cooperation. As a companion to the Road Map, WHO developed the *WHO Chemicals Road Map Workbook* which offers a structured way to work through the road map, choose priorities, and plan activities.

The Road Map has been recognized by stakeholders both within the health sector, and in other sectors, as useful for identifying actions for collaboration, and for advocating action from decision-makers.

**Table 2.1 Integrating chemicals and waste management, and green and sustainable chemistry innovation, in relevant economic sectors: some opportunities**

| Sectors | SDG targets | Examples of opportunities for management and innovation |
|---|---|---|
| **Agriculture and food** | Target 2.4: sustainable food production | Scale up Integrated Pest Management (IPM) and agroecological approaches, including development and use of non-chemical alternatives and other good agricultural practices |
| **Health** | Target 3.8: safe medicines and vaccines | Sound management of pharmaceuticals and disinfectants that contribute to antimicrobial resistance |
| **Energy** | Target 7.a: clean energy research and technologies | Improve technologies using resource-efficient, sustainable materials when decarbonizing the energy sector |
| **Infrastructure** | Target 9.1: sustainable infrastructures | Reduce raw material use and waste generation via advanced materials without creating future legacies |
| **Industry** | Target 9.2: sustainable industrialization | Ensure that chemical-intensive industries rely on best available techniques and best environmental practices |
| **Housing** | Target 11.1: safe housing | Reduce indoor air pollution through safer insulation and replace building materials of concern (e.g. asbestos) |
| **Transport** | Target 11.2: sustainable transport systems | Advance clean mobility, for example based on sustainable chemistry solutions for batteries |
| **Tourism** | Target 8.9: sustainable tourism | Adopt practices to reduce the chemical footprint of tourism services |
| **Mining** | Target 12.2: Sustainable use of natural resources | Ensure environmentally sound management of tailings |
| **Labour** | Target 8.8: safe working environments | Enhance risk assessment of chemicals of concern while promoting investment in green and sustainable chemistry to reduce hazardous occupational exposures |
| **Education** | Target 4.7: education for sustainable development | Mainstream green and sustainable chemistry into relevant curricula |
| **Finance** | Target 17.3: financial resources from multiple sources | Enhance use of green and sustainable chemistry metrics as criteria in investment |

The sectors, SDG targets and opportunities shown in this table are not exhaustive. Other relevant sectors include (but are not limited to) technology and innovation, labour, trade, development cooperation, and justice. Some of these sectors are discussed in section 2.2.2.

approach which could include the following considerations, among others:

- Identify industry sectors where chemicals and waste issues cause concern, including hot spots.
- Engage concerned industry sectors, associations and groups to initiate a dialogue.
- Ensure hazard and risk communication according to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS).
- Identify risk management approaches and opportunities for safer alternatives.
- Consider sectoral policy reform and standards to encourage sustainable chemistry innovation.

### International agreements can support policies and actions in economic sectors

In developing economic sector policies and actions, relevant Ministries may benefit from considering linkages with relevant international agreements on chemicals and waste. Examples of

**Table 2.2** **Examples of opportunities for the contribution of international chemicals and waste agreements across economic sectors**

| | International instrument | Examples of opportunities |
|---|---|---|
| UN environment Ozone Secretariat | Montreal Protocol on Substances that Deplete the Ozone Layer | Reduce use of ozone-depleting substances in insulation materials in the construction industry. |
| BASEL CONVENTION | Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal | Ensure that hazardous wastes and other wastes from all sectors are managed in an environmentally sound manner. |
| ROTTERDAM CONVENTION | Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade | Provide parties with opportunities to make informed decisions regarding imports of hazardous chemicals and pesticides (e.g. asbestos used in construction). |
| STOCKHOLM CONVENTION | Stockholm Convention on Persistent Organic Pollutants | Reduce use of persistent organic pollutants in agriculture. |
| MINAMATA CONVENTION ON MERCURY | Minamata Convention on Mercury | Control mercury-added products and manufacturing processes in which mercury or mercury compounds are used. |
| International Labour Organization | ILO Conventions concerning Safety and Health in Agriculture (No. 184), Safety in the use of Chemicals at Work (C170) and the Prevention of Major Industrial Accidents (C174) | Protect workers' health, e.g. in construction, agriculture and health care. |
| WHO | WHO International Health Regulations (IHR) (2005) | Ensure that up-to-date information is available on public health risks, e.g. pesticide poisonings. |
| | International Code of Conduct on Pesticide Management | Assist countries to develop improved registration processes for pesticides. |
| | Globally Harmonized System of Classification and Labelling of Chemicals (GHS) | Make hazard information available to relevant stakeholders. |

the opportunities that these instruments provide to advance sustainability in economic sectors are shown in Table 2.2. The IOMC participating organizations can also play a valuable role in facilitating the development of sectoral strategies, as well as in establishing and strengthening communication channels.

### 2.2.2 Integrating chemicals and waste management into enabling policies and actions

The 2030 Agenda also provides a renewed opportunity to strengthen inter-ministerial coordination to integrate chemicals and waste considerations into enabling sectors. Enabling conditions to advance sustainable development are promoted through a number of SDGs and targets, including those on education, innovation and financing. Advancing innovative solutions through enabling policies and actions has significant potential to reduce chemical pollution, thus complementing traditional action to achieve the sound management of chemicals and waste. However, chemicals and waste considerations are often not explicitly mentioned and therefore may not be addressed in relevant implementation plans.

### Strengthening green and sustainable chemistry education

Green and sustainable chemistry education has received increasing attention in recent years. However, gaps remain in further mainstreaming green and sustainable chemistry into curricula and replicating successful models, particularly in developing countries. Building on existing initiatives, further efforts are needed at all levels to mainstream green and sustainable chemistry education into chemistry and other education curricula and teaching, including gathering and disseminating best practices and forging new and strengthened partnerships at the national, regional and global levels.

### Strengthening research and innovation policies and programmes

Numerous innovations in green and sustainable chemistry have been developed, commercialized, or are on the horizon that illustrate the potential of chemistry to make a contribution to sustainable development. Entrepreneurs, start-up initiatives and collaborative innovation mechanisms are emerging as new tools and actors to address legacies and advance innovative solutions. Yet innovations in chemistry may also have unintended and undesirable effects, and linkages between innovators and the chemicals and waste community are not sufficiently developed. Opportunities to drive innovation in the desired direction, and strengthen collaborative innovation for green and sustainable chemistry, include the following:

- Integrate green and sustainable chemistry considerations into enabling policies, subsidy schemes or technology programmes.
- Apply green and sustainable chemistry principles or considerations to drive innovation in the desired direction.
- Strengthen the innovation ecosystem, including through public research funding.

### Scaling up financing and fiscal incentives

Significant financial resources have been mobilized from various sources. However, the Integrated approach to financing the sound management of chemicals and waste has not been fully implemented. Limited progress has been made by countries in integrating chemicals and waste into their development plans and/or priorities; external funding has not matched the need and demand for support expressed by developing countries and economies in transition; and gaps remain in regard to increasing industry contributions to match responsibility and the required level of support. Further steps to scale up financing and fiscal incentives beyond 2020 could include the following:

- Use linkages with the SDGs to secure national and dedicated external financing.
- Promote extended producer responsibility and internalization of costs by industry.
- Explore new opportunities such as sovereign wealth funds, philanthropic finance, and strengthened engagement of the financial sector and investors.
- Scale up the use of market-based instruments.

### Strengthening access to information, participation and access to justice

Providing enhanced access to robust information by workers, consumers and citizens, as well as fostering understanding of this information, is a prerequisite for ensuring effective public participation and informed decision-making and thus achieving the sound management of chemicals and waste. However, workers, consumers, citizens and other stakeholders still lack access to important information that would allow them to make informed decisions. In addition, they may not have access to justice. Enabling policies, including worker, consumer and community right-to-know, public participation, and access to justice, coupled with innovative technologies, can help reap the full potential for consumers, workers and citizens to engage and to protect their rights to a healthy environment while taking account of legitimate commercial confidentiality needs. As stated in the Overarching Policy Strategy, "information on chemicals relating to the health and safety of humans and the environment should not be regarded as confidential", while also "taking account of legitimate commercial confidentiality needs" (SAICM Secretariat, UNEP and WHO 2006). Relevant measures to empower and protect workers, consumers and citizens include the following:

› Develop and strengthen worker, consumer and community right-to-know policies and laws.

› Ensure access to justice in matters of chemical pollution and human health protection related to chemicals and waste.

› Ensure that consumers, workers and citizens have access to robust information, including through new information technologies.

## 2.3 Strengthening corporate polices

The 2020 goal cannot be achieved without strengthened action in the private sector, including the chemical industry, downstream manufacturers, and retailers. Many companies in chemical-intensive sectors, including the chemical industry itself, product manufacturers and retailers, have taken actions to strengthen chemicals and waste management. Initiatives include voluntary standard-setting beyond compliance, implementation of business models reducing the use of chemicals of concern in processes (e.g. Chemical Leasing), scaling up of efforts to develop green and sustainable chemistry alternatives, and commitments to phase out chemicals of concern in consumer products. Despite these efforts, voluntary actions and sustainability strategies beyond compliance that advance sound chemicals management are not yet being sufficiently developed and replicated, particularly in developing countries. Furthermore, important private sector stakeholders are not yet fully engaged in relevant discussions at the national and international level. Strengthening corporate commitment at the highest level is therefore essential.

## 2.4 Developing a coherent and results-oriented global indicators and reporting framework

### Establishing linkages across relevant agreements and initiatives

Governance under the current international framework for chemicals and waste management is characterized by an institutional architecture with a number of distinct indicator and reporting frameworks in place, making systematic assessment of progress and identification of the overarching priorities challenging (Honkonen and Khan 2017). The development of a framework for chemicals and waste beyond 2020 provides an opportunity to create linkages across all relevant agreements and initiatives related to chemicals and waste management. Of particular value would be a comprehensive framework bringing together and complementing chemicals and waste multilateral environmental agreements (MEAs) and other relevant instruments and initiatives, without interfering in matters addressed though these specialized instruments. Metrics and sustainability reporting that document progress and strengthen the accountability of the private sector could add further value and become an important aspect of measuring progress.

### Towards a common agenda to guide actions beyond 2020

An overarching common vision, strategic goals (or strategic objectives), targets and indicators to achieve sound management of chemicals and waste could provide a common agenda, guiding actions towards a desirable future in line with the 2030 Agenda. Specific chemicals and waste targets could address legacies and foster innovative solutions, creating a common agenda to which each stakeholder can contribute

**Box 2.2 The integrated results and indicator framework under the Strategic Plan for Biodiversity**

In 2010 Parties to the Convention on Biological Diversity adopted the Strategic Plan for Biodiversity, which comprises a shared Vision, a Mission, five Strategic Goals and 20 targets, collectively known as the Aichi Targets. The Aichi Targets provide a coherence, results and indicators framework, as well as a reference point for developing National Biodiversity Action Plans. They have been endorsed by all key international agreements in the area of biodiversity and by key actors. The Parties to the various MEAs in the biodiversity field have also agreed to work together in advancing an integrated indicators framework.


The Biodiversity Indicators Partnership (BIP) is the principal mechanism to measure progress in achieving the Aichi Targets and provide cross-mapping to the SDGs. It also supports progress reporting for other biodiversity related MEAs. The BIP incorporates more than 60 indicators, mostly reflecting monitoring data, in an integrated framework including 10 official SDG indicators. The partnership includes, inter alia, NGOs, universities, research institutes, secretariats of relevant MEAs, and other intergovernmental bodies, including the UN Statistical Division.

A key feature is that there are active institutions which take responsibility for the continued production and communication of certain indicators. The BIP also provides support to countries in order to strengthen capacity at the national level. In collaboration with partner organizations, the BIP has successfully mobilized action to track changes in biodiversity (Tittensor *et al.* 2014; Butchart, Di Marco and Watson 2016). The outcomes of work undertaken under the BIP serve as important inputs for the *Global Biodiversity Outlook*, which is produced periodically.

based on individual strengths and capacities. Reference to principles agreed during major international conferences (e.g. those in the 1992 Rio Declaration) could provide points of reference underlying actions by all stakeholders. Valuable lessons can be learned from the development of the Aichi Targets and the Strategic Plan for Biodiversity 2011-2020, which created an integrated and coherent international framework endorsed by all stakeholders in the biodiversity cluster (Box 2.2).



### Making country reporting meaningful

In order to inform national action, reporting schemes need to be simpler, country-driven and linked to global targets. Making reporting more meaningful could be achieved by using reporting data more systematically to monitor progress over time and across countries, identify best practices, and inform capacity building measures. Useful examples include the WHO International Health Regulations (IHR) model, reflecting progress with core capacities over time; the Aichi Targets, which provide a reference point for developing National Biodiversity Action Plans; and the United Nations Framework Convention on Climate Change, by means of which country reports are linked to international action.

### Consolidating national data and making them available at the global level

Better accessibility and understandability of reporting information can help measure progress and identify good practices. This, in turn, can promote learning, facilitate action at the national level, and engage different stakeholders with the instruments designed for the sound management of chemicals and waste. Moreover, such a function could provide a way for the public, nationally as well as globally, to engage in implementation in a meaningful way and to demand action and accountability. Consolidating reporting mechanisms and data from various instruments, focusing on a limited number of indicators, and making this available at the global level, as done, for example, in the case of the Global Health Observatory, would help to ensure accountability, track progress, engage stakeholders and identify good practices (Secretariat of the Vienna Convention and the

**Table 2.3 Example of a results chain to minimize adverse impacts**

| Activities | Outputs | Outcomes | Impacts |
|---|---|---|---|
| › Develop GHS awareness-raising and capacity building materials<br>› Prepare an implementation strategy for the GHS in key sectors | › GHS standards and regulation developed<br>› Key stakeholders trained and have capacity to implement the GHS | › GHS labels and safety data sheets available at the workplace<br>› Companies and workers take precautionary measures | › Reduced number of deaths and illnesses among workers and minimized impacts on the environment |

Implementation of the GHS is a necessary, but in many cases not sufficient measure for reducing the number of deaths and illnesses among workers and minimizing impacts on the environment.

Montreal Protocol 2018). The Montreal Protocol Ozone Data Center is another example of a useful implementation information system (WHO 2018).

### Towards a results framework that distinguishes measures taken and impacts

A coherent framework would benefit from distinguishing between outputs (e.g. adoption of legislation) and impacts (e.g. reduction of adverse impacts from hazardous chemicals), using impact indicators, where possible, to determine whether interventions are successful. Most indicators currently used to monitor progress under international chemicals and waste agreements are output-, activity- or instrument-based, making it difficult to assess progress in protecting human health and the environment from the adverse effects of chemicals and waste. A number of intergovernmental organizations (e.g. World Bank 2007; UNDP 2011; OECD 2017) have identified the usefulness of considering a results chain in measuring progress against agreed objectives.

In developing the framework, consideration also needs to be given to impact-focused targets in the 2030 Agenda. Concerning activity and output indicators, work under SAICM could serve as a starting point. It provides an example of indicators distinguishing between activities, outputs, outcomes and impacts to illustrate such a results chain. Further thinking could explore a comprehensive framework at the national level, as well as the interface of such a framework with tracking of progress at the global level. Important lessons can be learned from the global biodiversity cluster (Table 2.3).

# 3/ Engaging all sectors and actors in chemicals and waste management beyond 2020

## Mobilizing additional stakeholders to shape chemicals and waste management beyond 2020

Protecting human health and the environment from the adverse effects of chemicals and waste requires the engagement of all relevant stakeholders at the national, regional and global levels. This includes not only the chemicals and waste community, such as Ministries of Environment and Health, intergovernmental organizations, civil society organizations engaged in chemicals and waste, the chemical industry and trade unions, but also actors in key economic and enabling sectors, some of which have so far not been sufficiently engaged. To advance ambitious and concerted commitment, a global collaborative framework for the sound management of chemicals and waste would need to create mechanisms and incentives to foster the commitment and engagement of sectoral Ministries, retailers, downstream manufacturers and academia, as well as the broader global community.

## Further engaging key economic and enabling sectors

Despite some efforts and success stories in reaching out to and engaging stakeholders in economic sectors, limited progress has so far been made at the national and global level. Stakeholders may wish to consider the following

measures to further engage key economic and enabling sectors beyond 2020:

- *Strengthen partnerships through intergovernmental organizations*: Building on ownership and competitive advantages in the respective sectors, these organizations could take further steps to integrate chemicals and waste into their work streams and projects (as for example done with the WHO Chemicals Road Map). The IOMC organizations play an important role by providing the critical links to engage relevant sectoral Ministries already working on chemical and waste issues, as well as other stakeholders. Action plans could be drawn up to strengthen the chemicals and waste dimensions in the respective sectors.

- *Focusing on specific sectors*: Attention and resources could be mobilized in a more efficient and effective manner by focusing on specific economic sectors at a given point in time. For example, yearly themes could be organized through SAICM, starting, for example, with the construction sector.

- *Developing sectoral strategies*: Ministries of Environment and Health could take the lead in reaching out to sectoral Ministries in order to develop joint strategies for the integration of chemicals and waste issues in relevant national strategies and budgeting. This could be embedded in a global framework, providing overarching international strategies to advance the sound management of chemicals and waste in each sector.

## Further engaging companies, industry groups and trade associations

The private sector has a critical role to play, not only in addressing past legacies and preventing future ones but also in advancing innovative solutions to maximize the benefits of chemistry. Stakeholders may wish to consider the following measures to further engage key companies, industry groups and trade associations beyond 2020:

- *Creating a platform for frontrunners*: Giving a public platform to frontrunner retailers and downstream manufacturers that are excelling through innovative action to reduce the use of chemicals of concern, in order to showcase their achievements, may prove a useful tool to reward and further strengthen commitment and to motivate other companies to adopt similar practices, thus triggering a "race to the top". Governments would have the possibility to require, at some stage, that the practices of frontrunners are to apply to all players in the field concerned.

- *Strengthening voluntary standards*: The private sector can further step forward and show leadership by developing and implementing voluntary standards beyond compliance. These could be developed in close collaboration with the public sector and civil society, in order to enhance transparency and effectiveness.

- *Replicating innovative business models*: Efforts can be made to gather and share, also internationally, best practices in implementing innovative business models, and to replicate them, particularly in developing countries. North-South (as well as South-South) public-private partnerships could be established for this purpose.

## Further engaging the academic and research community

The full potential of the academic community to provide data and knowledge to inform decision-making has not yet materialized, given insufficient communication and engagement. Stakeholders may wish to consider the following measures to further engage the academic and research community beyond 2020:

- *Providing incentives for scientists*: Scientists may be more interested and motivated to provide targeted and tailor-made inputs for chemicals and waste policymaking if concrete reward structures are in place. This could include focusing the criteria of science funding agencies more on the sustainability aspect, and on giving due prominence to contributions made which advance sustainability.

- *Involving scientists*: Proactive efforts can be made to foster dialogue between scientists and policymakers, including by inviting scientists to participate more prominently in relevant fora and thus give them a voice, e.g. in bodies implementing or overseeing national and international instruments, in science-based projects implemented by intergovernmental organizations, and in industry initiatives.

- *Improving communication with scientists*: Policymakers could inform scientists more systematically about their needs, e.g. by writing guest articles in scientific journals or by speaking at academic conferences. Moreover, bodies could be established to organize regular exchanges between scientists and policymakers, both at the national and international level.

### Further engaging the donor, investor and financial communities

The integrated approach to financing the sound management of chemicals and waste provides a valuable framework; however, insufficient resources have so far been mobilized and there is a need for new sources of financing as well as building capacity for innovative financing, which may include cost recovery systems and placing responsibilities on industry. Stakeholders may wish to consider the following measures to further engage the donor, investor and financial communities beyond 2020:

- *Mobilizing new donors*: The linkages between chemicals and waste and the SDGs provide a valuable opportunity to tap into the large pools of funding available for implementation of the 2030 Agenda for chemicals and waste related projects in a wider context. This linkage can be particularly valuable in mobilizing resources from global public as well as private funds, including philanthropic finance. For example, linkages between chemicals and clean energy

© IISD/ENB, HRH Princess Laurentien of the Netherlands with Forum participants at the 2nd Global Session UN Science-Policy-Business Forum on the Environment, Nairobi, Kenya (enb.iisd.org/unep/science-policy-and-business-forum/2)

© Programa de las Naciones Unidas para el Desarrollo (PNUD) Peru/Monica Suarez

could help mobilize resources from the Green Climate Fund.

- *Mobilizing new business angels and investors*: There are significant opportunities, for example, to link promising start-up companies in the field of sustainable chemistry with investors that base their decisions on sustainability criteria. Bringing these potential business angels into the chemicals and waste community could prove a win-win situation.

- *Identifying new sources of financing*: Institutional investors have a large untapped potential to finance interventions for the sound management of chemicals and waste. It may thus prove beneficial to reach out to public pension funds and sovereign wealth funds and offer them investment opportunities that meet their sustainability criteria.

## Engaging leaders in the media

Stakeholders may wish to consider the following measures to further engage leaders in the media beyond 2020:

- *Scaling up collaboration with the media*: Media outlets continue to play a critical role in placing topics on the national and international agenda. Strengthened engagement of the media can help not only to multiply the effect of campaigns, but also to facilitate a more systematic information flow to ensure that citizens are able to track progress in reducing the adverse effects of chemicals and waste and exert pressure on regulators and the private sector.

- *Implementing campaigns to stimulate action on priority topics*: The “Beat Plastic Pollution” and “Detox” campaigns are only two of many examples demonstrating the potential of public campaigns to raise awareness. Such campaigns can mobilize stakeholders and unite them behind a common goal at the local, national, regional and global levels.

# References

## Chapter 1

Allen, C., Metternicht, G. and Wiedmann, T. (2018). Prioritising SDG targets: assessing baselines, gaps and interlinkages. *Sustainability Science* 1-18. https://doi.org/10.1007/s11625-018-0596-8.

Axon, S. and James, D. (2018). The UN Sustainable Development Goals: how can sustainable chemistry contribute? A view from the chemical industry. *Current Opinion in Green and Sustainable Chemistry* 13, 140-145. https://doi.org/10.1016/j.cogsc.2018.04.010.

Barbier, E.B. and Burgess, J.C. (2017). The Sustainable Development Goals and the systems approach to sustainability. *Economics Discussion Paper* 11(2017-28), 1-22. https://doi.org/10.5018/economics-ejournal.ja.2017-28.

BASF (2018). UN Sustainable Development Goals. https://www.basf.com/en/company/sustainability/employees-and-society/goals.html. Accessed 15 September 2018.

CropLife International (2019). Ensuring the sound management of pesticides: CropLife International commitment to the Strategic Approach to International Chemicals Management (SAICM). https://croplife.org/crop-protection/regulatory/product-management/strategic-approach-to-international-chemicals-management/. Accessed 25 February 2019.

Dow (2018). 2017 *Dow Sustainability Report*. https://www.dow.com/en-us/science-and-sustainability/highlights-and-reporting.

Elsevier (2018). 4th green & sustainable chemistry conference. https://www.elsevier.com/events/conferences/green-and-sustainable-chemistry-conference. Accessed 15 September 2018.

European Chemical Industry Council (2016). *Teaming Up for a Sustainable Europe: Cefic Sustainability Charter*. http://www.cefic.org/Documents/RESOURCES/PositionPapers/Cefic-Sustainability-Charter-TeamingUp-For-A-SustainableEurope.pdf.

Farrelly, M. (2016). Agroecology contributes to the sustainable development goals, 22 September. *Ileia*. https://www.ileia.org/2016/09/22/agroecology-contributes-sustainable-development-goals/. Accessed 15 September 2018.

Government of Canada (2018). *Canada's Implementation of the 2030 Agenda for Sustainable Development: Voluntary National Review*. Ottawa: Global Affairs Canada. https://sustainabledevelopment.un.org/content/documents/20033CanadasVoluntaryNationalReviewENv6.pdf.

Government of China (2016). *China's National Plan on Implementation of the 2030 Agenda for Sustainable Development*. https://www.fmprc.gov.cn/mfa_eng/zxxx_662805/W020161014332600482185.pdf.

Government of Thailand (2017). *Thailand's Voluntary National Review on the Implementation of the 2030 Agenda for Sustainable Development*. United Nations. https://sustainabledevelopment.un.org/content/documents/16147Thailand.pdf.

Government of the Federal Republic of Nigeria (2017). *Nigeria: Sustainable Development Goals (SDGs) Indicators Baseline Report 2016*. Abuja: Office of the Senior Special Assistant to the President on SDGs and National Bureau of Statistics. http://www.ng.undp.org/content/dam/nigeria/docs/SDGs/Nigeria%20SDGs%20Indicators%20Baseline%20Report%202016.pdf.

Hitce, J., Xu, J., Brossat, M., Dublanchet, A.-C., Philippe, M. and Dalko-Csiba, M. (2018). UN Sustainable Development Goals: how can sustainable/green chemistry contribute? Green chemistry as a source of sustainable innovations in the cosmetic industry. *Current Opinion in Green and Sustainable Chemistry* 13, 164-169. https://doi.org/10.1016/j.cogsc.2018.06.019.

Hoff, H. and I. Lobos Alva (2017). *How the Planetary Boundaries Framework Can Support National Implementation of the 2030 Agenda*. SEI Policy Brief. Stockholm: Stockholm Environment Institute, Stockholm. https://www.sei.org/mediamanager/documents/Publications/SEI-2017-PB-Hoff-HowthePlanetary.pdf.

International Council of Chemical Associations (2017). *Global Chemical Industry Contributions to Sustainable Development*. https://www.icca-chem.org/wp-content/uploads/2017/02/Global-Chemical-Industry-Contributions-to-the-UN-Sustainable-Development-Goals.pdf.

International Organization for Chemical Sciences in Development (2018). Current activities: chemists for sustainability, 5 November. http://www.iocd.org/WhatWeDo/Current/sustainability.shtml. Accessed 20 November 2018.

International POPs Elimination Network and Pesticide Action Network (2017). *Beyond 2020 Perspectives*. http://ipen.org/documents/ipen-beyond-2020-perspectives.

Inter-Organization Programme for the Sound Management of Chemicals (2017). *IOMC Plans for Future Actions to Implement the Goals and Targets of the 2030 Agenda*. Secretariat of the Strategic Approach to International Chemicals Management. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_7_IOMC.pdf.

Inter-Organization Programme for the Sound Management of Chemicals (2018). *Chemicals and Waste Management: Essential to Achieving the Sustainable Development Goals (SDGs)*. http://www.who.int/iomc/Chemicals_SDGs_interactive_Feb2018.pdf.

Kaduna State Government (2017). *Kaduna SDG Report*. https://kdsg.gov.ng/download/kaduna-sdg-report/.

Kuruvilla, S., Hinton, R., Boerma, T., Bunney, R., Casamitjana, N., Cortez, R., Fracassi, P., Franz-Vasdeki, J., Helldén, D., McManus, J., Papp, S., Rasanathan, K., Requejo, J., Silver, K.L., Tenhoope-Bender, P., Velleman, Y., Wegner, M.N., Armstrong, C.E., Barnett, S., Blauvelt, C., Buang, S.N., Bury, L., Callahan, E.A., Das, J.K., Gurnani, V., Kaba, M.W., Milman, H.M., Murray, J., Renner, I., Roche, M.L., Saint, V., Simpson, S., Subedar, H., Ukhova, D., Velásquez, C.N., Young, P., Graham, W. and PMNCH Multisectoral Collaboration Study Group. (2018). Business not as usual: How multisectoral collaboration can promote transformative change for health and sustainable development. *British Medical Journal* 363(k4771), 1-10. https://doi.org/10.1136/bmj.k4771.

Machingura, F. and Lally, S. (2017). *The Sustainable Development Goals and Their Trade-Offs: Case Study Report*. London: Overseas Development Institute. https://www.odi.org/sites/odi.org.uk/files/long-form-downloads/the_sdgs_and_their_trade-offs.pdf.

Matlin, S.A., Mehta, G., Hopf, H. and Krief, A. (2015). The role of chemistry in inventing a sustainable future. *Nature Chemistry* 7(12), 941-943. https://doi.org/10.1038/nchem.2389.

Morton, S., Pencheon, D. and Squires, N. (2017). Sustainable Development Goals (SDGs), and their implementation. *British Medical Bulletin* 124(1), 1-10. https://doi.org/10.1093/bmb/ldx031.

Nieuwenkamp, R. (2017). Ever heard of SDG washing? The urgency of SDG due diligence, 25 September. *OECD Development Matters*. https://oecd-development-matters.org/2017/09/25/ever-heard-of-sdg-washing-the-urgency-of-sdg-due-diligence/. Accessed 15 September 2018.

Pradhan, P., Costa, L., Rybski, D., Lucht, W. and Kropp, J.P. (2017). Earth's future a systematic study of sustainable development goal (SDG) interactions. *Earth's Future* 5(11), 1169-1179. https://doi.org/10.1002/2017ef000632.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. and Foley, J.A. (2009). A safe operating space for humanity. *Nature* 46(7263), 472-475. https://doi.org/10.1038/461472a.

Secretariat of the Strategic Approach to International Chemicals Management (2018). *The Contributions of the Basel, Rotterdam and Stockholm Conventions to the Sound Management of Chemicals and Wastes*. http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_INF_4_BRS_.pdf.

Singh, G.G., Cisneros-Montemayor, A.M., Swartz, W., Cheung, W., Guy, J.A., Kenny, T.-A., McOwen, C.J., Asch, R., Geffert, J.L., Wabnitz, C.C.C., Sumaila, R., Hanich, Q. and Ota, Y. (2018). A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals. *Marine Policy* 93, 223-231. https://doi.org/10.1016/j.marpol.2017.05.030.

Statistics Denmark (2018). Data – target 12.4: responsible management of chemicals and waste. https://www.dst.dk/en/Statistik/Sdg/12-ansvarligt-forbrug-og-produktion/delmaal-04/indikator-1#istart. Accessed 15 September 2018.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., De Vries, W., De Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B. and Sörlin, S. (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, 347(6223). https://doi.org/10.1126/science.1259855.

Stockholm Resilience Centre (2016). How food connects all the SDGs. http://www.stockholmresilience.org/research/research-news/2016-06-14-how-food-connects-all-the-sdgs.html. Accessed 31 August 2018.

Stibbe, D. (2018). Building the collaborative world we need to deliver the SDGs, 16 January. *The Partnering Initiative*. https://thepartneringinitiative.org/news-and-views/tpi-blog/building-the-collaborative-world-we-need/. Accessed 15 September 2018.

Sumitomo Chemical Group (2018). Sumitomo Chemical Group's contributions to the Sustainable Development Goals (SDGs). https://www.sumitomo-chem.co.jp/english/csr/management/sdgs/contents.html. Accessed 15 September 2018.

Textile Exchange (2018). What are the SDGs. https://textilesforsdgs.org/. Accessed 15 September 2018.

Ugarte, S., D'Hollander, D., Tregurtha, N. and Haase, N. (2017). *SDGs Mean Business: How Credible Standards Can Help Companies Deliver the 2030 Agenda*. Jeffries, B. (ed.). Gland: WWF-World Wide Fund for Nature. http://d2ouvy59p0dg6k.cloudfront.net/downloads/wwf_iseal_sdg_2017_28_feb.pdf.

United Nations Global Compact and Accenture Strategy (2016). *The UN Global Compact-Accenture Strategy CEO Study – Agenda 2030: A Window of Opportunity*. https://www.accenture.com/t20161216T041642Z__w__/us-en/_acnmedia/Accenture/next-gen-2/insight-ungc-ceo-study-page/Accenture-UN-Global-Compact-Accenture-Strategy-CEO-Study-2016.pdf.

United States Government Accountability Office (2018). *Chemical Innovation: Technologies to Make Processes and Products More Sustainable*. https://www.gao.gov/products/GAO-18-307.

Verles, M. and Vellacott, T. (2018). *Business and the Sustainable Development Goals: Best Practices to Seize Opportunity and Maximise Credibility*. Geneva: Gold Standard. https://www.wwf.ch/sites/default/files/doc-2018-02/18_02_15_SDG_Goldstandard%20Report.pdf.

VinylPlus (2018). VinylPlus contribution to the sustainable development goals. https://vinylplus.eu/community/sustainable-development-goals. Accessed 15 September 2018.

World Business Council for Sustainable Development (2017). *Chemical Sector SDG Roadmap*. https://www.wbcsd.org/Programs/People/Sustainable-Development-Goals/Resources/Chemical-Sector-SDG-Roadmap.

World Business Council for Sustainable Development and Radley Yeldar (2017). *Reporting Matters: Striking a Balance between Disclosure and Engagement*. https://docs.wbcsd.org/2017/10/WBCSD_Reporting_matters_2017_interactive.pdf.

World Economic Forum (2018). *Chemistry and Advanced Materials – Collaborative Innovation towards the Sustainable Development Goals*. Forthcoming report.

## Chapter 2

Butchart, S.H.M., Di Marco, M. and Watson, J.E.M. (2016). Formulating smart commitments on biodiversity: lessons from the Aichi targets. *Conservation Letters* 9(6), 457-468. https://doi.org/10.1111/conl.12278.

Honkonen, T. and Khan, S.A. (2017). *Chemicals and Waste Governance Beyond 2020: Exploring Pathways for a Coherent Global Regime*. Copenhagen: Nordic Council of Ministers. https://doi.org/10.6027/tn2017-502.

Organisation for Economic Co-operation and Development (2017). *Strengthening the Results Chain: Synthesis of Case Studies of Results-Based Management by Providers*. https://www.oecd.org/dac/peer-reviews/results-strengthening-results-chain-discussion-paper.pdf.

Secretariat of the Strategic Approach to International Chemicals Management, United Nations Environment Programme and World Health Organization (2006). *Strategic Approach to International Chemicals Management: SAICM Texts and Resolutions of the International Conference on Chemicals Management*. Geneva: United Nations Environment Programme. https://sustainabledevelopment.un.org/content/documents/SAICM_publication_ENG.pdf.

Secretariat of the Vienna Convention and the Montreal Protocol (2018). Ozone Secretariat: country data. https://ozone.unep.org/countries. Accessed 11 September 2018.

Tittensor, D.P., Walpole, M., Hill, S.L.L., Boyce, D.G., Britten, G.L., Burgess, N.D. Butchart, S. H.M., Leadley, P.W., Regan, E.C., Alkemade, R., Baumung, R., Bellard, C., Bouwman, L., Bowles-Newark, N.J., Chenery, A., M., Cheung, W.W.L., Christensen, V., Cooper, H.D., Crowther, A.R., Dixon, M.J.R., Galli, A,. Gaveau, V., Gregory, R.D., Gutierrez, N.L., Hirsch, T.L., Höft, R., Januchowski-Hartley, S.R., Karmann, M., Krug, C.B., Leverington, F.J., Loh, J., Lojenga, R.K., Malsch, K., Marques, A., Morgan, D.H.W., Mumby, P.J., Newbold, T., Noonan-Mooney, K., Pagad, S.N., Parks, B.C., Pereira, H.M., Robertson, T., Rondinini, C., Santini, L., Scharlemann, J.P.W., Schindler, Stefan., Sumaila, U Rashid., Teh, Louise S L., van Kolck, Jennifer., Visconti, Piero., Ye, Y (2014). A mid-term analysis of progress toward international biodiversity targets. *Science* 346(6206), 241-244. https://doi.org/10.1126/science.1257484.

United Nations Development Programme (2011). *Outcome Level Evaluation: A Companion Guide to the Handbook on Planning Monitoring and Evaluating for Development Results for Programme Units and Evaluators*. http://web.undp.org/evaluation/documents/guidance/UNDP_Guidance_on_Outcome-Level%20_Evaluation_2011.pdf.

World Bank (2007). *Module 2: Results Chain*. http://siteresources.worldbank.org/INTUKRAINE/Resources/328335-1212401346836/Module2ResultsChainEng.pdf.

World Health Organization (2018). Global Health Observatory (GHO) data. http://www.who.int/gho/en/. Accessed 11 September 2018.

# Index

2020 goal, 8-9, 17, 235-239, 241-242, 257, 260, 286, 330, 334, 585, 642-643, 647

2030 Agenda for Sustainable Development, 2, 6, 8-9, 17, 21, 63, 226-227, 239-240, 433, 509, 524-525, 628-654

Accidents, 68, 116-118, 157-158, 172, 250, 453-467

Adverse Outcome Pathway (AOP), 319, 389-390, 395, 409, 412

Africa, 27-28, 48-49, 62-63, 66-67, 75-76, 109-110, 114-115, 138, 171, 232-235, 252-253, 260, 264-266, 270, 273, 276-290, 297-298, 301, 440, 464, 511, 552, 560, 561, 576

Agroecology, 72, 437

Alternatives, 70-74, 293-294, 299, 302, 307-310, 385, 424-429, 431-433, 435-452, 472

Antibiotics, 100-101, 311-312

Antimicrobial resistance (AMR), 73, 101, 149-150, 254, 311-313, 413, 644

Arsenic, 103, 123, 133, 145, 152, 154, 157, 322, 335

Artisanal and small-scale gold mining (ASGM), 53-54, 97, 103, 142, 158, 249, 283, 466-467

Asbestos, 31-32, 56-57, 70, 150-152, 157-163, 170-173, 270-273, 644-645

Asia, 25-28, 35, 46-49, 58-59, 63-67, 70-76, 96-97, 107-110, 115, 171, 232, 248, 253-256, 258-260, 264, 266, 276-290, 296, 300-301, 323-324, 464, 510, 511, 576

Automotive, 30, 59, 69, 76, 80, 114, 304, 306, 428, 543, 545, 569

Basel Convention, 7, 115, 119, 220-221, 229-233, 238, 244-245, 250, 257, 267, 280-288, 297, 332, 433, 645

Benefits of action, 20, 164-175, 268

Beyond 2020, 2, 5, 9-13, 17, 20-21, 239, 275, 333-334, 388-389, 394, 402, 416-417, 427-428, 511, 585, 602, 632, 646-647, 651-654

Bisphenol, 83, 85, 107, 120, 123, 143-144, 149, 154-155, 322-323, 336-337, 437, 443, 551

Business models, 19, 65, 298, 533, 539, 542-554, 556, 647, 652

Cadmium, 54-55, 72, 74, 95, 101, 104, 112, 129, 131, 133-134, 145, 149, 157, 324, 338-339

Canada, 48, 50, 55, 70, 103, 111, 126, 128, 137-138, 142-143, 162, 258, 262, 263, 270, 285, 290, 310, 314, 319, 329, 386, 388, 394, 408, 410, 416-417, 517-518, 535, 561, 594-596, 633

Chemical industry, 2, 10, 24-40, 41-60, 61-67, 93-94, 113, 115-116, 157, 277, 282, 424-425, 427-428, 462, 504-505, 510-515, 528-529, 538-539, 548-549, 565-570, 576-585, 593, 601-602, 635, 647, 651

Chemical leasing, 19, 434, 542-545, 554, 582, 647

Chemicals in products, 78, 81-88, 104, 119, 253, 290-292, 298, 302-307, 397, 404-405, 418, 425, 431, 435-437, 566, 570, 574, 591, 603

China, 25-28, 35, 38-40, 43, 46, 49-52, 54, 55-59, 64, 67, 70-76, 79-80, 99-100, 102, 106, 109, 112, 114-116, 182,132-138, 141-143, 172, 253, 262, 266, 284, 297, 301, 303, 309-310, 319, 324, 328-329, 388, 432, 446, 455, 460, 462, 465, 517-519, 547, 550, 561-562, 593, 595, 598, 633

Circularity, 12-13, 86-91, 110, 305, 307, 471, 473, 505, 542, 568, 571-574, 631, 634

Citizens, 20, 144, 398, 586-603, 646-647, 654

Construction, 2, 12, 29-30, 59, 67-71, 76, 90, 102, 108, 118, 156, 159-160, 307, 464, 505-506, 643, 645, 652

Consumers, 12, 18, 20, 62, 77, 80-83, 88-90, 123-124, 298, 303-307, 396-397, 404, 420-425, 431, 434-435, 442, 510, 526, 539-540, 548-552, 565-569, 576, 580-583, 586-596, 603, 646-647

Coral reefs, 147-148

Corporate Social Responsibility, 462, 576-577, 602

Cosmetics and personal care products, 2-3, 30-32, 44, 59-60, 69-70, 83, 99, 105-106, 124, 128-130, 155, 161, 283, 325-326, 328-329, 592, 594, 596,

Costs of inaction, 20, 164-175, 268

Dichlorodiphenyltrichloroethane (DDT), 43-44, 47, 85, 96, 127-128, 130, 133, 135, 138-140, 146, 149, 152, 154, 315, 326, 506-507

Digitalization, 65, 511-514

Dubai Declaration, 7-8, 225, 263

Due diligence, 39, 303, 457

Ecosystem, 72-73, 103, 146-148, 163-164, 166, 170, 173-174, 297, 326-327, 397, 400-401, 412-413, 444, 469-473

Eco-industrial parks, 462-463, 539-540, 546-548, 554

Education, 8, 12, 19, 227, 261-262, 299, 306-307, 464, 509, 515-523, 525-526, 534, 540, 571, 590, 592, 630, 636, 641, 644-646

Effectiveness evaluation, 96, 233, 247-248

Electronic and electrical products, 2, 29-30, 51-53, 59, 68-72, 79, 84, 160, 290-292, 295-298, 303-307, 425, 442, 446, 560, 567, 569, 596

Emerging policy issues (EPIs), 267, 269, 290--319, 320, 333

Endocrine-disrupting chemicals (EDCs), 3, 147-148, 152-154, 157, 161, 163, 170-172, 290-292, 311, 315-319, 322-323, 328-329, 392, 395, 426, 443, 594

Entrepreneurs, 519, 523, 524-541, 551-554, 646

Europe, 3, 25-26, 28, 39-40, 46-50, 58, 63-54, 73, 95-97, 102, 113, 115, 124-126, 128, 130-131, 138, 144, 146-147, 168, 170-172, 232, 248, 254-256, 264, 266, 276, 283, 284-285, 288, 309, 386-388, 394, 398, 408, 412, 424-425, 432, 507, 510-511, 587, 594

European Chemicals Agency (ECHA), 90-91, 255, 262, 263, 270, 306, 324, 387-388, 391-392, 394, 416, 431,439, 551, 572

European Union, 3, 26-28, 39-40, 50-51, 55, 64, 88, 90, 100, 107, 113-114, 116, 158, 163, 169, 172, 248, 254-255, 259, 262-263, 269, 286, 290, 297, 303-304, 310, 314-315, 318, 322, 324, 327-329, 386, 391-392, 394, 398, 401, 408, 410, 420, 429-430, 436, 438, 442, 445-446, 455-456, 470, 522, 524, 551, 572, 585, 633

Exposure assessment, 19, 82-83, 90-91, 120-125, 143-144, 162-163, 164-167, 169, 173-175, 262-263, 276, 292, 316-319, 384-385, 389, 394, 396-405, 406-418, 419-434, 438, 468-473, 642

E-commerce, 65, 90, 283, 550-551, 554

E-waste, 109, 112, 115, 134, 166, 286, 465, 562

Feedstocks, 28-34, 41, 45, 59, 66, 68, 505, 507-510, 516, 530, 549, 565-566, 574, 595

Financing, 8, 18, 273-282, 289, 331-333, 433, 524-541, 547, 630-631, 641, 645-646, 653-654

Fiscal incentives, 18, 74, 553, 555-563, 646

Flame retardants, 50-51, 71, 83, 85-86, 105-106, 112, 115, 128-131, 133, 141-142, 152, 297, 425, 432, 437, 442-443, 561

Food and Agriculture Organization (FAO), 104, 224, 234-235, 238, 267, 270-272, 290, 299-302, 324, 413, 434, 636

Frontrunner companies, 9, 19, 21, 424, 442, 577, 652

Global Environment Facility (GEF), 249, 257, 261, 267, 278-280, 321, 331

Global Plan of Action (GPA), 8, 225, 237-239, 242, 259-261, 266, 272-273, 277

Globally Harmonized System of Classification and Labelling of Chemicals (GHS), 7, 18, 224, 234-235, 237-239, 242, 253-257, 263-264, 315, 331-332, 391-393, 395, 412, 417, 421-426, 430, 433-434, 569, 644-645, 650

Glyphosate, 47, 104, 155, 323, 324, 337

Green chemistry, 8, 18-19, 76, 431, 469, 504-511, 515-523, 525, 532, 539, 541, 565, 573-574, 582, 595, 636, 643-644, 646-647

Hazard assessment, 3, 18, 90, 263, 384-395, 412, 414, 416, 431, 439, 642

Hazardous waste, 5-6, 53, 92, 102, 108-115, 119, 146, 159, 161, 221, 236, 240, 244-245, 284-286, 287-288, 297-298, 331-332, 448, 463, 561

Health Canada, 258, 324

Health sector, 10, 32, 73, 226, 239, 261-262, 459, 643, 644-645, 652

Heavy metals, 6, 31-32, 52-55, 76, 87, 95, 101, 104, 108, 112, 129, 131, 133-135, 145-147, 149-150, 160, 162, 283, 324-325, 635

International Labour Organization (ILO), 5, 7, 157, 159, 222, 229-231, 238, 250, 333, 392, 398-399, 421, 462, 465, 594, 636, 645

Indicators, 17, 20, 225, 227, 228-240, 242, 245, 282, 287-288, 334, 575-585, 593, 637, 641, 647-650

Innovation, 3-4, 8, 12, 18-19, 61-68, 69-77, 243, 424, 426, 428-429, 424, 438, 440, 442-443, 447, 472-473, 506-517, 525-541, 542, 545, 547, 556-557, 572-573, 631, 634, 636, 638-639, 644-646

Integrated pest management, 73, 224, 281, 302, 433, 444-445, 450, 506, 644

International Code of Conduct on Pesticide Management, 7, 11, 224, 234-235, 238-239, 270-273, 299, 301, 331, 643

International Conference on Chemicals Management (ICCM), 2, 7-9, 225, 235, 238, 263, 267, 269, 280, 286, 288, 290-293, 296, 299, 303, 307, 311, 314, 316, 320, 437

Inter-Organization Programme for the Sound Management of Chemicals (IOMC), 21, 228, 234, 236, 238-239, 260-261, 266-267, 272-273, 276, 280-281, 288, 290, 300, 331, 433-434, 631, 636, 645, 652

Johannesburg Plan of Implementation (JPOI), 5, 7-8, 224-225, 241, 263-265

Latin America and the Caribbean, 25, 28, 40, 46-49, 57-58, 63, 66, 68, 72, 109, 128, 139, 145, 171, 248, 256-257, 260, 264, 276-277, 279, 285-286, 288, 511, 589

Lead, 5, 12, 52-53, 71-76, 85, 87, 89, 94-95, 101, 103-104, 107-108, 112, 115, 123, 126, 129, 131, 134, 137-138, 144, 145, 150-152, 154-163, 170-172, 238, 253, 269, 272-273, 277, 290, 293-295, 321, 325, 339-340, 556, 560

Legacies, 4, 18, 43, 62, 74-75, 108, 127, 131, 135, 141, 145-146, 248, 294-295, 514, 632, 644, 646, 648, 652

Life cycle assessment and management, 5, 13, 18-20, 78, 81, 86-91, 224-226, 237, 240, 262, 275, 333, 401-402, 420, 433, 438-442, 445, 468-473, 583-584

Market-based instruments, 90, 168, 432-433, 555-563, 646

Megatrends, 2, 14, 61-77, 110

Mercury, 53-54, 71, 83, 87, 95, 97, 101, 103-104, 106, 108, 112, 115, 118, 123, 128, 131-132, 134, 136-137, 142-144, 145, 149, 154-155, 158, 160-163, 168-170, 223, 245, 248-250, 269, 278-279, 288, 440, 451, 466, 645

Microbeads and microplastics, 60, 83, 85, 102, 104, 133, 135, 137, 149, 321, 325-326, 340-341, 596

Minamata Convention on Mercury, 54, 168, 170, 220, 223, 229, 234, 248-250, 265, 279-280, 332, 333, 433, 440, 446, 451, 466, 590, 645

Montreal Protocol on Substances that Deplete the Ozone Layer, 7, 94, 147, 168, 221, 229-320, 243, 267, 278-279, 284, 288, 332, 334, 426, 428-429, 433, 436, 446, 450, 645, 650

Multilateral treaties, 7, 44, 168, 220-223, 228-234, 237, 239-240, 241-251, 286, 321, 332-333, 647

Nanotechnology and manufactured nanomaterials, 28, 40, 51-52, 154, 290-292, 313-315, 386, 388, 393, 403, 407-408, 422, 423-424, 505, 514, 530

National profiles, 238, 259-262, 331, 333

Neonicotinoids, 85, 123, 148, 326-327, 341-342, 597

North America, 25-28, 40, 46, 48, 50, 54, 57-58, 64, 66, 73, 97, 102-104, 126, 128, 133, 136, 143, 145, 147, 166, 257-258, 266, 323, 445, 510-511

Occupational health and safety, 75, 89, 165, 167, 250, 275, 280-281, 307, 420, 434, 461-464, 467,

Ocean dead zones, 146-147

Organisation for Economic Cooperation and Development (OECD), 25, 76, 111, 116-118, 143, 158, 163, 168, 175, 235, 238, 240, 254, 257-259, 263, 267, 272, 286, 290, 301, 305, 307, 314-315, 331, 386, 388-390, 392-393, 401-403, 409-410, 416, 418, 424, 426, 432, 434, 438, 445, 454-458, 508, 636

Overall Orientation and Guidance (OOG), 8, 225, 235, 237-240, 241-242, 263, 266, 272-273, 33, 631, 641

Overarching Policy Strategy (OPS), 7-8, 225, 259, 261, 263, 274, 282, 285-286, 289, 291, 330-331, 590-591, 631, 647

Ozone depleting substances (ODS), 94, 118, 229, 243, 278-279, 332, 428, 551, 556, 560, 645

Persistent organic pollutants (POPs), 7, 43, 68, 95-96, 101, 118, 126-128, 130-131, 134-135, 138-139, 144, 149, 152, 154-155, 223, 229, 246-248, 265, 267, 278-279, 280-281, 301, 332, 398, 444

Per- and polyfluoroalkyl Substances (PFASs), 50, 76, 129, 135, 140, 292, 307-310

Perfluorooctanoic acid (PFOA), 50, 85, 99, 130, 133, 140-141, 152, 154, 168, 172, 309-310,

Perfluorooctanesulfonic acid (PFOS), 50, 99, 128, 130-131, 133, 136, 140, 141, 152, 309-310

Pesticides, 7, 31-32, 46-48, 65-68, 72-73, 85, 93, 98, 100-104, 113, 116, 118, 123-135, 145-163, 223-224, 234, 238, 247, 237, 269, 270-273, 281-286, 288, 290, 292, 299-302, 314, 318, 324, 331, 332, 337, 341-342, 396-397, 409, 420, 422-423, 432-434, 444-445, 464-465, 469, 506, 512-513, 556, 558-559, 590, 595, 634-635, 645

Pharmaceuticals, 3, 24, 41-43, 48-50, 59, 64, 68, 73-74, 100, 114-115, 130-132, 147, 154, 263, 310-313, 400, 504-505, 513, 550, 644

Phthalates, 71, 83, 85, 87-88, 98, 106-107, 123-124, 129, 142, 144, 149, 152, 154-155, 161-162, 171, 315, 328-329, 344-345, 425, 429, 443, 560-561, 563, 594

Plastic, 29-33, 37, 42, 44, 56-60, 70-71, 80-90, 101-102, 104-105, 107-112, 115, 123-124, 131, 133-135, 137, 148-150, 152, 162, 324, 325-326, 328, 340-341, 399, 504-507, 530, 549-552, 558, 560-561, 596-597, 654

Plasticizer, 83-85, 88, 105, 124, 152, 328, 443, 594

Pollinators, 148, 301, 327

Pollution, 10, 12, 62, 67-68, 70, 76-77, 90-91, 92-119, 126, 133, 146-147, 150-152, 155, 160-162, 164-165, 169-170, 174, 240, 265, 296, 324-325, 431, 438, 464, 508-509, 512, 515, 542-543, 546, 556, 562, 584, 592-593, 599, 601, 603, 646-647, 654

Poisoning, 72, 112, 150-151, 154, 158-159, 240, 266, 273, 300, 423, 444, 465, 645

Poisons centres, 237-238, 273, 331-332

Pollutant Release and Transfer Registers (PRTRs), 6, 93, 95, 103, 113-114, 118-119, 238, 257, 265-266, 305, 307, 331-332, 400, 403, 592-593

Polychlorinated biphenyls (PCB), 43, 85, 87, 95-96, 112, 124, 127-128, 130-131, 133-135, 138-140, 147, 149, 152, 154-155, 158, 160, 162, 235, 247-248, 315, 326, 456

Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), 86-96, 127, 134, 138-140, 309

Polycyclic aromatic hydrocarbons (PAHs), 85-86, 95, 112, 130, 149, 162, 328, 343-344

Product life cycle, 78, 80-82, 86, 86-91, 121, 164, 220, 295-298, 302-307, 400, 405, 442, 468-473, 564, 568, 572-573

Quick Start Programme (QSP), 236, 260-261, 275, 277, 279-281, 330-331

Resource efficiency, 4, 11, 13, 68, 75, 86, 115, 512, 542, 544, 554, 571-572, 578, 583

Responsible care, 35-36, 277, 282, 426-427, 577, 596

Rights, 226-227, 509, 553, 583, 586-603, 647

Risk assessment, 5, 19, 74, 168, 237, 262-263, 266-269, 273, 312, 315, 320-321, 332, 384-388, 392, 403, 405, 406-418, 419-422, 429-436, 439, 441, 448, 458, 469, 472, 594, 642, 644

Risk management, 5, 19, 70, 163, 262-263, 268-273, 321, 332, 384-385, 407-408, 411-414, 419-434, 453-467, 564-566, 595-597, 603, 642, 644

Risk reduction, 8, 225, 236-237, 242, 269-273, 287-288, 289, 293, 301-302, 331, 458

Roadmaps, 20-21, 634, 643, 652

Rotterdam Convention, 7, 223, 228, 245-246, 250, 267, 282-284, 332, 444, 590, 645

Safety data sheet (SDS), 119, 224, 276, 304, 420-424, 459-460, 568-569, 590,594, 650

Science-policy interface, 20, 267-268, 331, 642

Sectors, 2, 10, 19, 21, 28-32, 59, 61-62, 68-77, 88, 227, 251, 259, 261-263, 303, 305-306, 424, 427-428, 472-473, 505-506, 508-509, 514, 525, 528-529, 539, 558, 563, 568, 578-581, 585, 630-632, 638-640, 641-647, 651-654

Small and medium-sized enterprises (SMEs), 36, 38, 89, 156, 281, 294-295, 428, 438, 445, 459-464, 467, 549-551, 554, 578

Social entrepreneurship, 542, 551-552, 554

Special Programme, 280, 331

Standard-setting, 19, 425-426, 427-428, 462, 647, 652

Start-ups, 19, 451, 525-541, 646, 654

Stockholm Convention on Persistent Organic Pollutants, 7, 43-44, 50-51, 95-96, 118, 126-131, 138-140, 144, 152, 223, 229, 231-233, 246-248, 250, 261, 265, 267, 278-280, 288, 301, 309, 332-333, 398, 426, 432-433, 436, 444, 637, 645

Strategic Approach to International Chemicals Management, 2, 5, 7-9, 13, 91, 220, 224-226, 228, 235-238, 239, 242, 250-251, 260-263, 266-267, 269, 272-277, 279-290, 291-292, 302-303, 305-307, 321, 325, 330, 334, 459, 511, 569, 585, 590-591, 631-632, 641, 650, 652

Substances of very high concern, 91, 255-256, 258, 269, 306, 310, 329, 424, 429, 563, 572, 592, 594

Substitution, 19, 73, 169, 306, 323, 420, 424-425, 429, 435-452, 468, 473, 543, 547, 556-557, 642

Supply chain, 2, 19-20, 29, 35, 71, 78-91, 107, 156, 160, 297, 302-307, 399, 426, 431, 443, 448-449, 466-467, 470-473, 513, 564-574, 576-579, 583, 588

Sustainability assessment, 425, 427, 468-473, 568

Sustainable chemistry, 8, 18-19, 62, 76, 278, 468-469, 504-414, 515-523, 524-541, 563, 565-566, 573-574, 582-583, 635-636, 643-644, 646-647, 654

Textiles, 2-3, 9, 30, 50-51, 59, 68-69, 76-77, 80, 83, 86, 102, 105, 109, 125, 137, 156, 159-160, 303, 307, 310, 314, 325, 428, 435, 505, 579, 593, 635, 643

Toys, 79-81, 83, 85, 105, 160, 283, 299, 303-304, 307, 324-325, 328, 553

Triclosan, 83, 123, 131, 144, 149, 154, 161, 329, 346

Unintended contaminants, 85-89, 119, 568

United Nations Conference on Environment and Development (UNCED), 5, 220, 265

United Nations Conference on Sustainable Development (Rio+20), 6, 12

United Nations Development Programme (UNDP), 238, 249, 274, 636

United Nations Environment Programme (UNEP), 3, 7, 12, 149, 152, 166, 234-235, 238, 240, 250, 262, 274-277, 284, 290, 398, 433, 449, 454-455, 466, 511, 531, 569, 582, 591, 598, 636

United Nations Economic Commission for Europe (UNECE), 235, 324-325, 454, 589, 595,

United Nations Industrial Development Organization (UNIDO), 238, 249, 290, 434, 449, 519, 543-545, 588, 636

United Nations Institute for Training and Research (UNITAR), 260, 261, 272, 290, 466, 636

United States (US), 26-27, 33, 35, 38, 40, 43, 46-50, 52-56, 70-71, 83, 90, 95, 99-101, 103-104, 107, 109, 111, 113, 123-124, 126, 129, 133, 137, 141-144, 148, 154-155, 157, 161-162, 166, 168-169, 172-173, 257-258, 262, 290, 297, 303-304, 309, 314, 323, 329, 386-387, 391, 398, 401, 409, 413, 425, 427, 429, 436, 438, 446, 448, 451, 455, 458, 515, 523, 527, 532, 553, 560, 561, 566, 577, 580, 588, 591, 593-594, 596-598

United States Environmental Protection Agency (US EPA), 126, 143, 258, 262, 270, 284, 310, 387-388, 403, 408-409, 411, 431, 445, 449, 469, 507, 566, 569, 592, 595, 597

Value chain, 17, 24, 28-30, 35-26, 41-44, 78, 81-82, 93, 115, 164, 276, 307, 313, 428-429, 512-513, 529, 537, 569, 570, 579, 583, 596

Volatile organic compounds (VOCs), 95, 98, 105-106, 129, 170, 328, 550, 569

Voluntary instruments, 7, 220, 224, 234-235, 242

Waste hierarchy, 12-13, 63, 88

Workers, 10, 20, 70-71, 73, 81, 112, 125, 156-158, 160, 161, 222, 230, 250, 269, 294, 296-298, 315, 325, 386, 396-370, 398-399, 407, 415, 420-426, 448-449, 460, 464-467, 470, 523, 568, 586-603, 645-647, 650

World Summit on Sustainable Development, 5-8, 224

WHO International Health Regulations (2015), 7, 223, 229, 233-234, 238, 251, 454, 645, 649

World Business Council for Sustainable Development (WBCSD), 9, 21, 427, 634

World Health Organization (WHO), 7, 10, 21, 70, 99, 116, 123, 126, 130, 140, 149-150, 152, 157, 159, 161, 223, 233, 234-235, 238-240, 251, 266-267, 270, 272-273, 290, 299, 301, 311, 313, 315, 317, 321, 325, 331, 392, 409-410, 412-414, 417, 423-424, 434, 636, 643, 645, 649, 652


UN environment

United Nations
Environment Programme