UN environment

GEO-6

FOR INDUSTRY IN ASIA-PACIFIC

GEO-6 for Industry in Asia -Pacific

ISBN No: 978-92-807-3752-3
Job No: DEW/2239/BA

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Suggested citation:

UNEP 2019. GEO-6 for Industry in Asia-Pacific. United Nations Environment Programme, Nairobi, Kenya.

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Front Cover

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Global Environment Outlook 6
for Industry in Asia-Pacific

Edited by

UN environment

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Institute for Global Environmental Strategies

In collaboration with

teri
The Energy and Resources Institute

Tsinghua University 1911

ISPONRE Viet Nam

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FOREWORD

Asia and the Pacific's unrelenting industrial development has been a driving force in the economic growth of scores of countries in the region and beyond. This shift has led to greater prosperity, increased urbanisation and sustained population growth.

Yet as the region has become the "world's factory", it is increasingly realising not only the benefits but the challenges of industrial development. These challenges are often environmental in nature.

The 6th Global Environment Outlook, released earlier this year, showed us that sustainable development was at risk from a number of factors. Not least of these were unsustainable consumption and production patterns and large increases in resource use. This report, a special product of GEO-6, further examines how these environmental problems are caused - and can be addressed - by the region's rapid industrialisation.

A healthy environment and resilient ecosystems are the foundations of economic prosperity, human health and well-being. Currently, however, industrial use of natural resources is unsustainable and inefficient. Industrial pollution is a driver of climate change, biodiversity loss, and all of their attendant drawbacks.

The good news is that many countries in the region have recognised core problems and are moving forward in regulating industry, controlling industrial pollution and stemming wasteful resource use. But as with many environmental challenges, we must scale up our efforts and move much faster.

And there is more to uncover than the marquee environmental problems. Less well-known but just as significant are emerging issues such as pharmaceutical pollution, overuse of antibiotics, microplastics, genetic modification and nanotechnology. The region's policy makers must be alert to these emerging challenges and the different policy implications they bring.

This report has brought together the region's foremost environmental policy think tanks to both identify the challenges and help point the way forward. I hope that this analysis highlights the importance of continued research into the environmental impact of the region's industrialisation. And I hope its conclusions will enhance the innovative approaches, policies and practices, often pioneered by countries in Asia and the Pacific, that will be vital to achieving the Sustainable Development Goals.

Dechen Tsering

Regional Director
UN Environment Regional Office for Asia and the Pacific

INTRODUCTION

A core mandate of the United Nations Environment Programme (UNEP) in Asia and the Pacific is to keep the region's environment under review as outlined below.

- Global Environment Outlook (GEO) Asia and the Pacific: an integrated assessment conducted every 5 years in the region to report on the regional environmental situation, and to provide content for the global GEO assessment.
- Environment Live: an open on-line platform for sharing environmental data and other knowledge products; and supporting assessment and research.
- GEAS Alerts: short reports on environmental change, as they occur in locations in the region, and on emerging issues and threats in the region requiring urgent attention.
- Thematic assessments: conducted at regional and sub-regional levels to support government decision-making to address critical or emerging environmental issues in the region .
- Capacity-building in state of environment (SoE) and other environmental reporting, for example the Sustainable Development Goals (SDGs) and multilateral environmental agreements (MEAs) in the region.
- Facilitate implementation of other global programmes, for example the development of statistical methodologies for SDG indicators and Global Environmental Monitoring System (GEMS)/Water in the region.
- Science policy interface and policy impacts of different options.

The Asia-Pacific regional assessment for GEO-6, released in 2016, identified the region's rapid urbanisation and industrialisation as key drivers of environmental change affecting air, water, land and biota to varying degrees. The identified emerging issues have had less attention from policy makers to date and may be having silent impacts that will only be recognised when it is too late to prevent or avoid them. This brief e-report takes a deep dive into the subject of the impact of Asia-Pacific's rapid industrialisation on the region's environment, not just from the usual perspective of historical trends and known environmental impacts but also through a closer examination of emerging environmental issues of concern.

The first section of the report deals with the traditional state and trends examination that is expected in a GEO report, covering the impacts of industrialisation on climate change, air, water and biodiversity, but with a greater emphasis on emerging issues rather than historical trends. Industrialisation is treated sufficiently broadly to cover not only the manufacturing and energy sectors but also intensive agriculture, such as pig and poultry farming that have major impacts on the environment.

The chapter on climate change (Chapter 1) focuses on industrial energy efficiency as a critical pathway to reducing greenhouse gas emissions. Much of the current debate around climate change centres around mitigation through the promotion of renewable energy, whereas energy efficiency may be a low-hanging fruit for industry, with quick pay-back returns.

The chapter on air quality (Chapter 2) discusses the recent re-emergence of air pollution concerns. It also suggests that policymakers in the region will need to target multiple pollutants and multiple sources to address these concerns. This includes several sources that are not considered major contributors to air pollution such as waste and manure management. This chapter investigates whether the arrangements that are in place in Asia and the Pacific are adequate to address these pollutants or if are they being allowed to pass below the radar.

The twin issues of water scarcity and water quality are addressed in Chapter 3, with particular attention to groundwater depletion, emerging interest in fracking, industrial contamination of surface and groundwater, nutrient pollution from intensive agriculture and aquaculture, and low concentration contaminants that often escape wastewater treatment and ambient monitoring programmes. Different policy options for closing the gap between established measures and expected national targets on water quality and quantity are examined.

Chapter 4 examines how industrialisation contributes directly and indirectly to the loss of biodiversity – directly through the demand for resources from biodiverse regions and indirectly through emerging outputs of the industrial system such as genetically modified organisms. The use of clustered regularly interspaced short palindromic repeats (CRISPR) as a tool to manipulate DNA and the potential for the release of genetically enhanced food and animal products is addressed as a double-edged sword, having both the potential for great benefits and harm. The social and environmental impacts of these "enhanced" species and the need for new policy responses are examined as potential "sleeping" issues in the Asia-Pacific region.

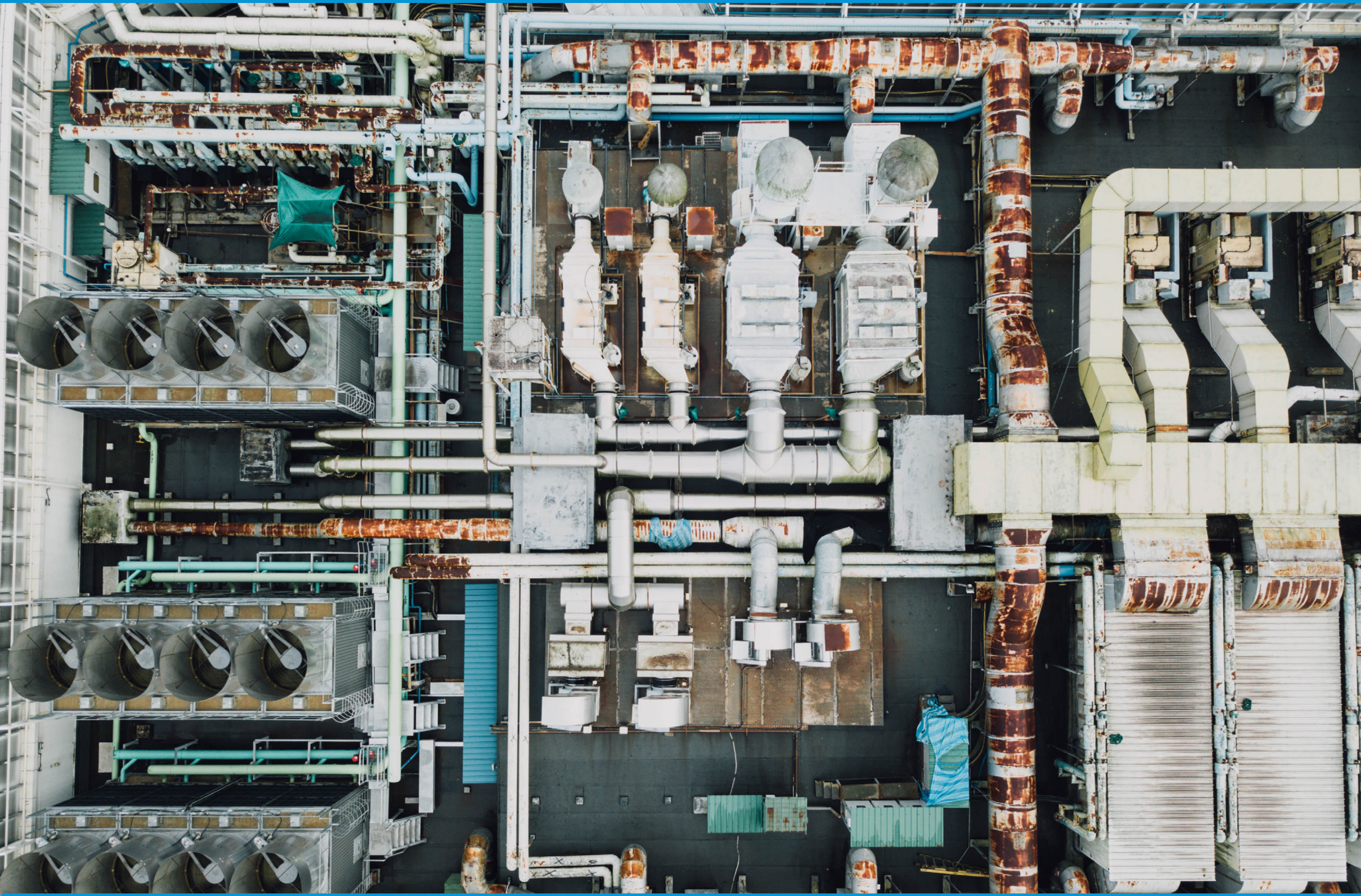
The second section of the report addresses some emerging pollutants from industry that need to be addressed in the immediate future. While these may currently not be the highest priority issues, they have potential to become major problems that will be quite difficult to solve. It is therefore important for policy makers to be aware of these emerging issues and make the necessary preparations for dealing with them before they develop into major environmental challenges.

Chapter 5 on electronic waste deals with a higher profile issue, and one which has regional implications since several countries are banning the importation of e-wastes. It also addresses the challenges of the 3Rs (reduce, reuse, recycle) in the face of consumer trends that demand the latest electronic products, well before usability of older products expires. An emerging issue that will require attention of policy makers in the near future is the burgeoning amount of used solar panels and batteries that are becoming increasingly difficult to recycle.

Chapter 6 extends the current concern over plastic pollution to the pervasive release of microplastics into marine and freshwater environments and the possibility that these tiny plastic particles could transfer toxic chemicals to fish and other aquatic organisms and ultimately to humans. The related issue of nanomaterials is also addressed briefly in this chapter, along with recommended policy options.

The final technical chapter (Chapter 7) examines the emerging environmental problems associated with pharmaceuticals, antibiotics and personal care products that are being detected in low concentrations in aquatic environments and drinking water, and can have adverse impacts on biota and potentially on human health. The excessive use of antibiotics in livestock animals and the potential transfer of antibiotic-resistant bacteria to humans is also highlighted, with policy options for their use and disposal discussed.

Chapter 8 discusses the research, policy, and regulatory implications of these emerging environmental issues, with the objective of making policy makers in the Asia-Pacific region more aware of these looming threats and preparing them for taking precautionary actions.



SECTION 1

Industrialisation and Its Impacts on the Environment

CHAPTER 1
Climate and Industrial Energy Efficiency

Authors: Ajay Mathur, Girish Sethi, N. Vasudevan (TERI, India)

Photo by Robin Sommer on Unsplash

KEY QUESTIONS

- What contribution can improvements in industrial energy efficiency make to reducing greenhouse gas emissions and meeting the Paris Agreement goals?
- What is the business case for energy efficiency improvements in various sectors? What are the advantages of focusing on cross-cutting technologies and best operating practices? What are the implications for industry in improving energy efficiency?
- What are some of the technological advances that make energy efficiency a truly low-hanging fruit? What will be the impact of robotisation in achieving increased energy efficiency?
- What is the role of energy auditing? What has been the experience of countries that have made energy audits mandatory?
- How important is a design-for-the-environment approach in new industrial plants to ensure that optimal energy efficiency is achieved? Are there some case examples?
- What are some of the environmental and social co-benefits that accompany energy efficiency improvements?
- What are some of the policy implications for governments?

Asia and the Pacific accounts for a significant share of global energy consumption, with a large part coming from the industrial sector. The region is made up of 58 economies and is home to around 60 per cent of the global population (UNESCAP 2013). Its share of the global purchasing power parity gross domestic product (GDP PPP) rose from 30.1 per cent in 2000 to 42.6 per cent in 2017 (ADB 2018), with three countries – China, India and Japan – accounting for more than 70 per cent of the region's total output in 2017. The region's energy consumption rose at about double the global rate in 2014; it consumes more than half of the world's energy supply and emits about 55 per cent of global emissions from fuel combustion (UNESCAP 2017). Industry in the region plays a vital role in the economies of its different countries due to its close links with their overall development. The share of energy consumption in Asia and the Pacific from coal, oil, gas and electricity increased from 32.7 per cent in 1990 to 38.1 per cent in 2014, reflecting progress in industrialisation, but also a corresponding increase in greenhouse gas emissions. Nonetheless industry's emission intensity in the major countries of the region has recently shown a promising downward trend – China, -20 per cent; India, -9.8 per cent; Japan, -2.7 per cent; and the Republic of Korea, -11.7 per cent (Climate Transparency 2018).

Industrial energy efficiency helps in achieving substantial benefits. Energy-intensive industry sub-sectors such as steel, cement, aluminium, chemicals, fertiliser, pulp and paper, and textiles account for a large share of energy consumption within the industrial sector. These industries require large energy inputs in different forms to produce one unit of their product, consuming thermal energy and/or electrical energy for their process requirements and operation of other related utilities. The growth of the industrial sector helps in improving the economy of a country but at the same time leads to increased energy consumption and greenhouse gas emissions. Adoption of energy efficient options in industry can be through different routes as shown in Figure 1.1. Other benefits associated with energy-efficiency improvements include enhanced energy security, environmental improvements in the workplace, new employment generation, emergence of energy-efficiency related business opportunities and improved product quality. When adopting energy-efficient technologies in an industry, reliability of the system is the most important factor since it directly impacts productivity. This aspect can be addressed through various means such as supplier guarantees for the technology/equipment, independent certification and third-party monitoring and verification.

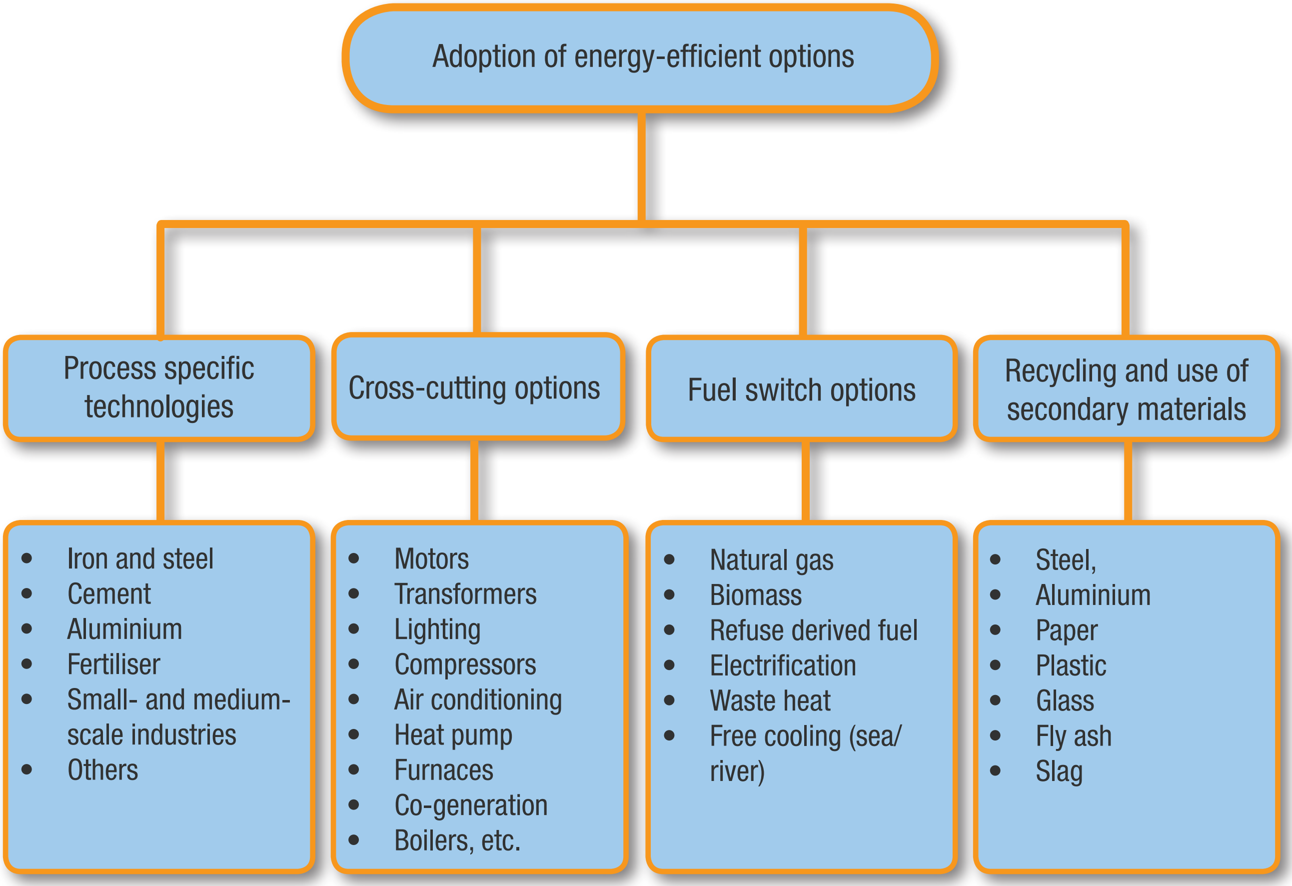


Figure 1.1: Energy efficient options

Source: Authors

Industry may have the highest potential of all sectors for energy end-use efficiency. A recent study on energy efficiency in India has found that the industrial sector has the potential to save 40.2 million tonnes of oil equivalent (Mtoe) by 2031, which is the highest among all energy end-use sectors in the country (TERI 2018). Different options available to the industrial sector for improving energy efficiency include:

i. process-specific technologies;
ii. cross-cutting technologies;
iii. fuel switches; and
iv. recycling and use of secondary materials (Figure 1.1).

Process-specific energy efficient technologies would help in significant reduction in specific energy consumption i.e. reducing the energy required to produce one unit of a product and hence overall energy consumption (IRENA 2018). This option, for example a "dry process" in the cement industry to replacing the current inefficient "wet process", would involve huge capital investments and relatively long paybacks. Fuel switching would help in the adoption of cleaner fuels along with associated energy and environmental benefits (IFC 2018). Recycling is one of the prominent options available for industries to reduce energy related emissions. In recycling, a used product or waste of a consistent quality is reprocessed which requires only a fraction of the energy needed for producing new products. Recycling helps in reducing energy consumption as well as preserving natural resources (US Department of Energy 2015). Improvements in energy efficiency are also in line with the Sustainable Development Goals (SDG 7: Affordable and clean energy).

Cross-cutting technological options and best operating practices are important in reducing energy consumption levels. Several types of equipment are used across different industrial sub-sectors. Many industries use inefficient equipment, which could be replaced with energy-efficient equipment. For example, electric motors are used in industries for a variety of applications such as fans and blowers used in boilers and furnaces, pumping systems and conveyors, etc. A study by the International Energy Agency (IEA) estimated that electric motors alone account for about two-thirds of industrial power consumption and about 45 per cent of global power consumption. Some other important cross-cutting technologies used in industries include compressed air, steam, refrigeration and air-conditioning and lighting systems, all of which offer good scope for improvements in energy efficiency. Some of the successful cross-cutting technology options include use of variable frequency drives (VFDs) in motors, reducing leaks in compressed air systems, improved insulation of hot/cold surfaces, and the use of LED lighting. Industries can also explore the use of waste heat for applications, such as district heating and cooling, wherever feasible.

Box 1.1 UJALA – A case study on energy efficient appliances and lighting in India

As part of its energy efficiency initiatives, India's Government launched a scheme called UJALA in 2015 with the objective of providing affordable appliances and lighting for all. It includes the distribution of energy-efficient tube lights, light-emitting diode (LED) bulbs and energy efficient fans across different states of India. UJALA is a highly successful ongoing scheme and by November 2018, the Government had distributed 313 million LED bulbs, 6.7 million energy-efficient tube lights and 2 million energy-efficient fans through its various distribution systems. The quantified achievements of the UJALA scheme at the national level are:

1. energy saving: 41.4 billion kilowatt hours (kWh) of electricity per year;
2. monetary benefits: USD 2.29 billion per year;
3. avoided peak demand for electricity: 8,377 megawatts (MW);
4. greenhouse gas reductions: 33.5 million tonnes of carbon dioxide per year.

Source: Energy Efficiency Services Limited 2018

Small-scale industry is a unique sector requiring an out-of-the-box approach to make a difference. Small-scale industries form the backbone of the economy in many Asia-Pacific countries (Asia Pacific MSME Trade Coalition 2018). They are extremely important as they provide employment to millions of people; yet these are generally neglected industries in terms of progress and modernisation. For example, small- and medium-sized enterprises (SMEs) in Thailand represent over 90 per cent of all businesses and provide employment to more than 60 per cent of the work force (Yamuna Rani Palanimally 2016). In China, there are about 11.7 million SMEs representing about 97 per cent of all industry and providing about 60 per cent of total GDP and 80 per cent of urban employment in 2013 (OECD iLibrary 2016). In India, there are around 63 million SMEs, of which 19.6 million are in the manufacturing sector, that generate about 29 per cent of GDP and employ more than 107 million people (MoMSME 2018). Industries including foundries, brick making, forging, and chemicals in the SME sector are energy-intensive but have not kept up with technological progress. Many of the small-scale industries exist in clusters, produce similar products and are very similar in terms of energy efficiency and operating practices. Some of the common factors among SMEs are:

i. a majority of SMEs use obsolete technology and have limited access to new and energy efficient ones;
ii. they lack financial and technical capacity to adopt energy-efficient technology or undertake research and development;
iii. in-house capacities of SMEs are limited on process and product innovation; and
iv. there is generally a low level of awareness on energy efficiency.

As a result, there is huge potential for energy saving in the small-scale industrial sector. Successful case studies in Asian countries show that barriers such as technology availability, service delivery system, internal capacity and financing, need to be overcome if traditional small-scale industries are to adopt energy-efficiency pathways.

Improvements in energy efficiency are paramount for sustainability of the SME sector due to increasing energy costs and competition at local and global levels. Energy efficiency improvements would help in:

i. reducing energy costs;
ii. improving the working environment, for example enhancing insulation in furnaces would lead to reduced temperatures in the workplace;
iii. reducing pollution at local levels and contributing towards overall greenhouse gas reductions; and
iv. enhancing competitiveness.

Programmes of, and interventions by, governments and various agencies focusing on technology development and demonstration, capacity building and training, and financing are primarily aimed at enhancing competitiveness and improving livelihood opportunities. SDG 8 focuses on promotion of inclusive and sustainable economic growth, employment and decent work for all; enhancing SMEs therefore directly promotes this SDG.

Box 1.2 Changing problems into opportunities – the Climate & Clean Air Coalition's experience in Nepal's brick industry

The earthquake in Nepal in 2015 caused vast damage to buildings and brick kilns as well. About 350 kilns were completely or partially destroyed, of which 105 were in the Kathmandu valley, leading to a large gap in supply of bricks for reconstruction. A project was set-up by the Climate & Clean Air Coalition (CCAC) to replacing damaged kilns with energy efficient ones. It introduced earthquake-proof zig-zag kilns and produced a technology manual for operators, the first of its kind in South Asia. Nine brick kilns have adopted the new design while other kilns have adopted brick stacking and firing techniques. The rebuilding costs were completely borne by the brick industry. An emission reduction of 60 per cent and a coal saving of about 20 per cent have been achieved with the new design and firing technique.

Source: Climate & Clean Air Coalition 2016

Energy auditing is a tool for delivering energy efficiency in industry. Energy auditing serves as a tool for industry to identify inefficiencies in their operation – both in process areas and various utilities (Kimura 2016). It helps management in identifying and prioritising energy efficiency options and achieving energy savings. By picking low hanging fruit such as reducing leaks, improving insulation of hot and cold surfaces and enhancing natural lighting, energy savings can be achieved in many areas at very low cost. In other cases, relatively greater investment will be needed to reduce energy consumption in various sections of a factory. Countries such as India have made periodic energy auditing mandatory to help identify options and then implement energy efficiency measures in large energy-consuming industries.

There are multiple benefits from energy audits. Energy audits deliver multiple benefits. Undertaking an energy audit in an industry helps:

i. identify inefficiencies in operation of process and connected utilities or auxiliaries;
ii. estimate energy losses in operation;
iii. quantify energy savings;
iv. identify energy saving opportunities at the plant level; and
v. prioritise energy efficiency options for implementation and achieve energy savings (UNDP 2018).

The energy savings identified through energy audit can be categorised as follows.

1. *Good housekeeping practices*: for example, reducing compressed air leaks, enhancing natural lighting and switching off lights. These generally involve no or low-level investment and lead to marginal energy savings.
2. *Retrofit or replacement of an inefficient system with energy efficient ones*: for example, installation of variable frequency drives (VFDs) in multi-pumping systems, improvement of insulation in furnaces, replacement of inefficient motors with energy-efficient ones, and use of online oxygen analyser-based control systems to optimise excess air in a boiler. These require medium-level investments and result in moderate energy savings.
3. *Revamping a system*: for example, the installation of energy efficient boilers in the chemical industry or switching from Soderberg to pre-baked processes in primary aluminum production. These are likely to require relatively large capital investment, planning and sometimes plant shutdowns.

Box 1.3 Best practices in air compressor helps in energy saving without any investments

A small-scale forging plant in India was using an air compressor of 3.5 kW rating and 22 cubic feet per minute of design capacity. The operating pressure of the compressor was set at 10 bar, which led to its continuous operation although the process requirement was only at 4.5–5 bar. Following an energy audit recommendation, the factory optimised its generation of compressed air at 5 bar, which led to energy savings of 6 800 kWh per year.

Source: TERI 2015

The design of new industrial plants should incorporate the highest efficiency standards. New capacity in different industrial sub-sectors should adopt state-of-the-art technologies and energy-efficiency solutions at the design stage. The selection of processes and technology in an industry is mainly based on the type of end-products manufactured, access to suitable raw materials and forms of energy, and environmental compliance. Other important considerations in the selection of technologies include the capital investment required for setting up a plant. Often industries prioritise capital costs to minimise investment on plant and machines, ignoring inefficiencies associated with the system (Oyedepo 2012). Some industries even opt to acquire second-hand plant in order to minimise initial investments.

Energy efficiency of the overall system is generally not given due importance, leading to poor energy performance and higher energy consumption during the life cycle of a plant. While raw materials and energy are external factors to industry, the most prominent internal option is incorporating energy efficiency at the design stage (European Commission 2009). Selection of state-of-the-art technologies includes the use of energy-efficient equipment and the incorporation of energy-efficiency measures based on the requirements of a plant. For example, the cement industry could install, as part of a technology package, waste-heat recovery (WHR) systems which utilise waste heat from process sections. A WHR system includes a waste-heat recovery boiler to generate steam and a turbo-generator of suitable capacity to generate electricity. Although this would involve comparatively higher initial investments, the benefits are many including the self-generated electricity that can be used to meet part of the plant's needs, thereby reducing the dependency on often unreliable grid power.

Re-using waste heat is also often a missed opportunity. Setting up innovative district energy systems that reuse industrial waste heat for nearby district heating and cooling should be explored. The development of modern energy-efficient, climate-resilient and affordable district energy systems is one of the lowest cost and most efficient solutions for reducing greenhouse gas emissions and primary energy demand. A transition to such systems, combined with energy efficiency measures, could reduce carbon dioxide emission in the energy sector by as much as 58 per cent by 2050 (UNEP 2015). District cooling has huge potential to reduce soaring electricity demand from air conditioning and chillers, which can present problems at times of peak load and require expensive transmission system upgrades, electricity capacity additions and decentralised backup generators to deal with prolonged blackouts (UNEP 2015).

Benchmarking of energy performance of processes and key equipment is an important activity that could help industries improve their performance (UNEP 2016). It would help in:

i. understanding the performance of a plant compared to its close competitors;
ii. comparing performance between parallel production lines or groups of companies;
iii. identifying specific areas for improvement; and
iv. undertaking remedial measures for performance improvement and move closer to benchmarks.

The role of robotics, automation and internet-of-things (IoT) solutions in energy efficiency is unfolding. Industrialisation involves a shift from labour-intensive production processes to the use of machinery – from semi-automatic systems through fully automatic ones to computerised control systems for a number of industrial applications, mainly in large- and, to some extent, medium-sized industries. Most the production processes of SMEs in the Asia-Pacific region, however, remain labour-intensive due to such factors as low labour cost, non-accessibility of high-end technologies, and the high investment required for automation.

There are potential advantages of using robotics and industrial automation in industry, such as:

i. increased productivity and reduced cycle time;
ii. improved product quality and manufacturing precision;
iii. reduced wastage; and
iv. decreased fatigue of workers, especially in tough environments such as close to a furnace.

Automation of industrial processes helps in controlling and managing key process/operating parameters close to design conditions, which may not be possible by manual means (European Commission 2016). Industry needs to adopt state-of-the-art control systems, such as neural networks or fuzzy logic, in manufacturing and integration with real-time monitoring and control of process variables, such as reactor temperatures, carbon levels, and oxygen control. Automation and the use of robotics are industry specific and hence require tailor-made technological solutions. The IoT is also finding widespread applications across various industries. It helps the manufacturing sector through increasing access to knowledge and information, reduced transaction costs and improved decision-making processes both across the industry and along the value chain. To reap the benefits of automation and the application of robotics, industry needs to make substantial investments and enhance in-house technical capabilities. These changes must be accompanied by re-training and courses for workers employed in those industries to upgrade their skills.

National and regional energy-efficiency targets are broad, ambitious and driven forward by the Paris Agreement. The central aim of the Paris Agreement is to strengthen the global response to the threat of climate change. It requires all Parties to put forward their best efforts through nationally determined contributions (NDCs) that outline and communicate their post-2020 climate action, and report regularly on their greenhouse gas emissions and their implementation efforts. Various countries have enacted laws and guidelines for reducing energy intensity of different end-use sectors, for example China's Energy Conservation Law, India's Energy Conservation Act and Japan's Energy Conservation Guidelines. These focus on the rational use of energy, strengthening energy-conservation management, formulating and implementing energy conservation plans and technological measures, and reducing energy consumption. For example, Japan's Energy Conservation Law (1979) focuses on energy end users, including factories, with the objective of introducing industry-specific energy management systems and embedding energy efficiency as a basic course of action for corporations (Institute for Industrial Productivity 2018). Japan has further developed Energy Conservation Guidelines for end-users to support implementation. Key government policies help set targets and encourage moving away from business-as-usual scenarios.

Box 1.4 Top-runner programme of Japan

Introduced in 1999 under the Energy Conservation Law , the top-runner programme is intended to improve the efficiency of energy-consuming products. The programme comprises a set of energy-efficiency standards covering energy-intensive products such as home appliances and motor vehicles; as of 2014, it includes 23 product categories. The inclusion of products is based on their energy use, widespread distribution or their scope for substantial energy-efficiency improvements. Targets, based of the most efficient models available, have to be achieved within a given timeframe.

The top-runner programme is overwhelmingly supported by manufacturers of the different products. They are directly involved in target setting and energy efficiency is considered to provide competitive advantage over other manufacturers. The targets are set taking account of the limits for potential improvement, while standards are set considering technological innovation and diffusion. A number of revisions pertaining to target products were made to the programme in 2005, 2009 and 2013.

Source: Ministry of Economy, Trade and Industry, Japan 2015

Many countries in the region have enacted national policies to promote energy conservation. India's Energy Conservation Act (2001) focuses on reducing energy intensity in different end-use sectors (The Gazette of India 2001). Under the Act, the perform, achieve and trade (PAT) scheme was launched providing industry-specific energy efficiency targets focusing mainly on large industries, thermal power stations and commercial establishments. As in Japan, India published Energy Conservation Guidelines for industries in 2018 (Bureau of Energy Efficiency 2018). China's Energy Conservation Law (1997) aims to promote energy conservation across society, improving energy utilisation and economic performance, while protecting the environment and ensuring socio-economic development and livelihoods. The law is intended to strengthen the administration of energy use, encourage the adoption of measures which are technologically and economically feasible and environmentally benign, reduce losses and waste in energy production and consumption, and ensure the more efficient and rational use of energy resources. It further encourages the development and use of new and renewable energy resources (Energy Conservation Law 2018). Thailand's Energy Conservation Promotion Act (1992) lays out the general scope, requirements and responsibilities for key energy-consuming sectors. All these laws mandate a reduction of energy intensity in different end-use sectors.

More attention is needed to address hard-to-abate sectors. Some industry sub-sectors face major challenges in switching or transiting from fossil fuels to low-carbon technologies in the long-term. The challenges are particularly acute in hard-to-abate sectors such as iron and steel, cement, petrochemicals and fertiliser production, where even the best available internationally-adopted technologies are still based on fossil fuels.

This is especially challenging for developing countries that are expected to grow at 8–10 per cent annually and have many new steel and cement plants that need to be set up in the coming years to meet the growing needs for infrastructure and housing. For example, India's steel policy envisages increasing its installed capacity from 100 million tonnes per annum (mtpa) to around 300 mtpa by 2030.

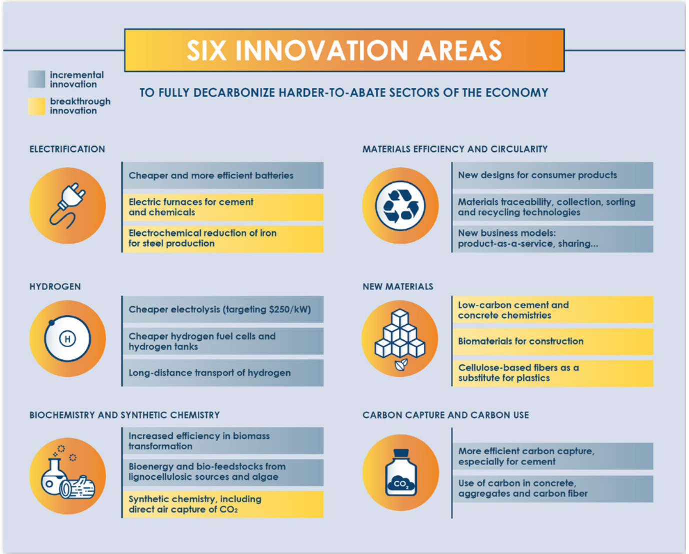


Figure 1.2: Six innovation areas for decarbonising hard-to-abate sectors

Source: Energy Transition Commission 2018

For successful energy transition in hard-to-abate sectors, low-carbon technologies of suitable scale should be readily available and affordable. Such technologies, however, are not commercially available at present; they are either at a conceptual stage, under research and development (R&D), or are simply not available. The development and commercialisation of low carbon technologies require radical, perhaps disruptive, innovation, long-term R&D and extensive trials/demonstrations, all involving large-scale investment that industry in developing countries may not be able or willing to make. Collaborative models involving industry, research and academic institutes, government and international agencies will be needed to drive this change. This may require a major shift in approach as well as fresh initiatives at policy and financial levels. A recent report by the Energy Transition Commission identified six innovation areas that would help in the complete decarbonisation of hard-to-abate sectors (Figure 1.2) (Energy Transition Commission 2018).

Implications for industry.

While some countries in Asia and the Pacific have enacted legislation for improving energy efficiency in the industrial sector, there is a need for widening and deepening the effective implementation of various programmes and schemes at national and regional levels. The high share of energy consumption and emissions by the industrial sector in the region demands commensurate actions by industry and governments to ensure that industrial development operates in a manner that is not detrimental to the environment in the long term. Long-term collaborative R&D and appropriate joint action are of paramount importance to address decarbonisation aspects in hard-to-abate sectors such as iron, steel, cement and plastics production.

Policy implications.

Despite energy efficiency being a low-hanging fruit, many industries have not adopted energy-efficient technologies voluntarily. In developing countries where the industrial sector is growing very rapidly, the main focus of many plants is increasing production levels – increasing production volumes to increase/retain market share in a competitive environment – rather than paying attention to the adoption of energy efficient technologies and equipment. Structured programmes could be launched by governments for wide-scale dissemination and adoption of energy-efficient technologies and best practices, including plant automation. Customised programmes in the small-scale sector could be formulated focusing on the demonstration of technology, capacity building and training along with suitable financing options. Tools like energy audits and efficiency standards for new equipment and plant, and regulations and appropriate business models for market aggregation also need to be in place.

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CHAPTER 2
Managing Air Pollution in Asia: Towards a Multi-Benefit, Multi-Source Strategy

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KEY QUESTIONS

- Atmospheric pollution has been a key environmental issue for more than 40 years, so why has it become an emerging concern again?
- What are the key impacts of air pollution and why are they so important?
- Are conventional pollution-control approaches still relevant or is a completely new approach warranted?
- Manufacturing industry and thermal power plants have been the main fixed sources of air pollution, but are there new emerging sources that should be of concern?
- What are some of the co-benefits of addressing air pollution?
- What are the main governance changes that need to be implemented to bring atmospheric pollution under control?

Air pollution has re-emerged as a serious threat to the health and well-being of much of Asia and the Pacific. Air pollution has gained prominence on the policy agenda of Asian governments over the last several years. Although control strategies have typically focused on addressing point sources from individual sectors, more integrated approaches to air pollution are receiving increasing attention (van Vliet *et al.* 2012). Indeed, whether it is coal-fired power plants or large-scale farming operations, many decision makers in the region have become convinced that they must act quickly and decisively to reduce emissions from a diverse range of sources. Current research underlines the urgency of this commitment: only 8 per cent of people in the region currently breathe air that is within standards for small particulate matter ($PM_{2.5}$) - 10 micrograms per cubic metre ($\mu g/m^3$) annual mean - set by the World Health Organisation (WHO) (UNEP APCAP CCAC. 2019). Other studies have shown that the most susceptible to air pollution are the elderly, children and the poor as they often live closer to pollution sources (Kan *et al.* 2012). There are also signs that air pollution is contributing to crop losses, threatening food security and exacerbating climate change. In short, multiple benefits can come from more integrated air pollution control strategies (UNEP APCAP CCAC. 2019).

There are many well-known proven solutions. Fortunately, growing concerns over air pollution have been met with efforts to better estimate impacts and identify solutions. A recent report published by UN Environment, the Climate Change and Clean Air Coalition (CCAC) and the Asia Pacific Clean Air Partnership (APCAP) outlined a set of 25 solutions that, properly implemented, could expand the number of people in Asia and the Pacific breathing air within WHO guidelines to around 1 billion by 2030. Reaching these levels would cut premature mortality by one third, while also reducing crop losses (maize, rice, soy and wheat) by 45 per cent. Such actions would also reduce emissions of carbon dioxide by 20 per cent and methane emissions by 45 per cent and greatly aid in efforts to limit temperature increases below the 1.5ºC level written into the Paris Agreement (IPCC 2018; UNEP APCAP CCAC. 2019).

Multiple benefits will require multiple solutions. Comprehensive pollution control strategies are required to target conventional sources of air pollution associated with power plants and heavy industry in addition to addressing the open burning of waste and managing manure more efficiently in the livestock sector and supporting a wider transition to renewable energy. Accordingly, some work suggests that there is scope to package a set of actions for driving reductions in both conventional and non-conventional sources of air pollution by focusing on multiple industries and sectors (Rogge and Reichardt, 2016).

New governance arrangements are essential for driving forward these solutions. Coordination across and within agencies - together with strengthened cooperation between national and local authorities, as well as other stakeholders - are becoming increasingly important to implement air quality initiatives. Consensus-based strategies such as these will be particularly important as countries continue to map their development pathways over the next 12 years - the time at which the Paris Agreement and the Sustainable Agenda for 2030 are set to close.

The primary purpose of this chapter is to demonstrate how different sets of air pollution solutions from a range of industries can be implemented in Asia and the Pacific. The chapter, drawing upon *Air pollution in Asia and the Pacific: science-based solutions (UNEP APCAP.* 2019), divides the solutions into three groups:

1. Conventional controls: this involves time-tested, end-of-the-pipe equipment installed on power plants and vehicles.
2. Next stage controls: this involves regulating sources that have not traditionally been the focus of the air pollution community, including farms and new industries.
3. Development priority measures: this involves introducing and scaling new technologies that create changes in the energy structure.

Conventional controls on power plants and industry mainly require stricter enforcement. Many governments have stiffened ambient standards and adopted plant-level standards that have led to significant reductions in emissions from large-scale energy and industrial sources of pollution. This is often achieved through national plans that require the uptake of end-of-the pipe control technologies. For example, in response to reductions targets on sulphur dioxide that China introduced as part of its 11th and 12th Five Year Plan there has been large-scale deployment of flue-gas desulfurisation (FGD) equipment that has contributed to its emission reductions. FGD has also become common in countries ranging from Thailand to the Republic of Korea (Wang *et al.* 2014; Simacha 2015). Other countries in the region have also relied on policy or legal reforms to induce and diffuse these kinds of controls. Japan's Law on Particulate Matter and Nitrogen Oxides, for example, has led to the spread of controls on nitrogen oxides at earlier stages than in many other developed regions (Popp 2006).

Policy reforms have also led to structural changes in polluting industries. China's air quality has benefitted from the consolidation and shutting down of small-scale industries – for instance, in the cement sector the proportion of large units producing more than 4 000 tonnes per day using pre-calciner kilns increased from 33 per cent to 60 per cent (Zhao *et al.* 2013). Meanwhile, India has seen the tightening of standards result in the shutdown of inefficient power plants and fuel switching (Patel, 2019). In India's capital, Delhi, the phasing in of stringent standards has resulted in the shutdown of power plants or a shift to gas as the fuel of choice. Japan has taken a slightly different approach that focuses on developing and submitting energy-savings plans, frequent inspections, and financial support for pollution abatement technologies for small-scale companies (Energy Conservation Centre of Japan 2011).

There is still scope for improvement when it comes to conventional controls. The installation of denitrification technologies, for example, has tended to lag behind FGD and electrostatic precipitators (MEP 2011). There is also room for strengthening policies that could lead to the adoption of emission controls. One of the challenges in India is the lack of standards at the emission-source level that would motivate the wider adoption and spread of control technologies among coal-burning power plants (Guttikunda and Jawahar 2014). Moreover, there are legitimate concerns that in fast growing countries there will be an increase in the construction and operation of these plants.

Open burning of waste is an underrated source of air pollution. Open burning of waste stems from the deliberate combustion of refuse materials and debris ranging from biomass, paper, plastics, textiles, oils, hazardous waste and other items to the incomplete combustion of similar items in substandard incineration facilities. Both types of combustion lead to formation of air pollutants that degrade air quality and contribute to near- as well as long-term climate change. Further, open burning can lead to the release of potentially toxic, carcinogenic and mutagenic persistent organic pollutants, such as polycyclic aromatic hydrocarbons, dioxins and furans, that can pose serious risks to soil, water, the food chain, and human health.

Open burning primarily stems from inadequate waste collection, treatment and disposal. Local waste management authorities are typically responsible for its regulation and control. Where successful, this has been achieved through expanded service provision of waste collection, along with increasing recycling and disposal capacities. Such local control often begins with appropriate waste management approaches and technologies, such as better separation of waste at source, ways to more effectively mobilise public sanitation workers and assessment options for waste treatment and disposal. These actions are, in turn, best combined as part of a longer-term strategy that is linked with national-level plans, and objectives for reducing waste generation and improving the use of resources. Other important success factors for reducing open burning and diverting waste from a landfill include technical cooperation from local, as well as regional public and private sector partners. When these elements are in place it can often lead to government budget savings and employment creation.

Box 2.1: The case of Mandalay, Myanmar

The city of Mandalay, Myanmar provides an instructive example of how improved waste management systems can limit air pollution. Faced with an escalating waste crisis, local authorities have been taking proactive steps to tackle the open burning of waste. In addition to the strict enforcement of bans on such practices, the effort also includes a new policy requiring source segregation of waste and the progressive introduction of separated waste collection systems for designated communities and schools. These activities are part of the city's longer-term vision set out by Mandalay's waste management strategy and action plan (2017–2030). A key feature of the strategy is its emphasis on public participation, encouraging collaboration between communities, civil society and businesses, including informal waste recyclers, in identifying challenges and devising solutions. Technical cooperation from local, as well as regional public and private sector partners, is likely to be instrumental in reducing open burning and diverting the total volume of waste sent to the landfill. Some calculations indicate that if Mandalay remains on course in implementing the strategy, the city will reduce upwards of 60 per cent of waste-related emissions by 2030.

Source: IGES-CCET 2018

Waste-to-energy incineration plants may not be the optimal solution everywhere. In some countries, there has been a shift to more capital-intensive waste management technologies such as waste-to-energy incineration plants. There is nonetheless a large body of evidence suggesting that these systems may not meet intended goals in industrialising countries because the majority of solid waste is organic with low calorific values and thus serves as a poor feedstock for combustion (Rand *et al.* 2000). Similarly, there is longstanding debate about whether incineration may have the unintended consequence of discouraging reuse, recycling and prevention practices (Malinauskaite *et al.* 2017). Some research indicates that incineration may also restrict potential employment opportunities from more labour-intensive waste management methods (European Commission 2018).

Livestock manure is an emerging concern in air pollution control. Managing manure from the livestock industry, including the proper treatment of excreta, urine and seepage, is increasingly viewed as critical to controlling air pollution. Manure and urine are sources of ammonia that contributes to the formation of secondary air pollution particles. Proper treatment of livestock manure can help to reduce the deposition of urea. Improved management practices may have other desirable side-effects such as the reduction of non-point source water pollution and the creation of high-quality organic fertiliser from the use of liquid digestive residue.

Some solutions involve reducing the amount of nitrogen in livestock urine. Diversifying the grazing areas and diets of cattle can lead to lower levels of nitrogen concentrations (Edwards *et al.* 2015). Other solutions have focused on the use of nitrogen inhibitors that can be applied to soils and alter the chemical breakdown of nitrogen into urea (Li *et al.* 2014). Solutions like these are still at the proof-of-concept stage and have not been applied at the scale of farms or farming communities (Selbie *et al.* 2015). Other solutions involve more systematically managing animal manure with greater efforts to regard manure as a resource rather than a waste. This is particularly important for large-scale cattle farms as they tend to be disconnected from farming operations that could use the manure as a fertiliser.

Another manure management technique involves encouraging anaerobic digestion. Dairy farming has a range of negative environmental impacts. To help reduce these impacts, biogas plants can be combined with composting facilities, making use of existing sludge treatment operations. Such plants enable biogas to be created through anaerobic fermentation of livestock excreta generated from neighbouring farms. Consisting of methane, carbon dioxide, moisture and trace amounts of hydrogen sulphide, the resulting biogas can be used as fuel to produce electricity. This can be achieved with the development of biodigesters as illustrated by Shikaoi, a town in Hokkaido, Japan, that relies heavily on dairy farming.

Box 2.2: The case of Shikaoi, Hokkaido, Japan

While improving manure management practice can help reduce ammonia losses and improve air quality, other benefits are often the main reason for changing these practices. In Shikaoi, Japan, a rural town that relies heavily on dairy farming, this was indeed the case. Approximately a decade ago, Shikaoi faced the unenviable challenge of managing manure from more than 18 000 dairy cows. To help address this challenge, Shikaoi established a biogas plant with a composting facility in an existing sludge treatment facility. The plant began operations in 2007 as the newly established Shikaoi Environmental Preservation Centre. In this plant, biogas was produced through anaerobic fermentation of livestock excreta collected from neighbouring farms. The biogas generated through this process consists of methane, carbon dioxide, moisture, and a small amount of hydrogen sulphide. The gas was used as fuel for electricity, hot water, and steam.

Source: ACP 2018

Renewable energy has multiple benefits. Renewable energy generated by solar and wind power can be instrumental in reducing energy poverty, strengthening energy security, curbing greenhouse gas emissions and controlling air pollution. Favourable market trends for renewable energy have spurred governments across the Asia-Pacific region to adopt policies supporting its promotion. While progress needs to be made in terms of grid access and distribution, renewable portfolio standards, feed-in-tariffs, other regulatory mandates and market-based programmes have been introduced in many countries, reflecting a gradual shift towards fossil-free sources of electricity (Figure 2.1). Against this backdrop, several smaller industrialising countries in the region are also leading efforts to bring more renewables into their energy mix. Malaysia has introduced specific feed-in-tariffs, coupled with net metering policies, to support the large-scale deployment of rooftop solar, while Brunei Darussalam has gone further, including implementing quotas, setting up a certificate trading system and supporting other guarantees on renewable energy supply (IRENA

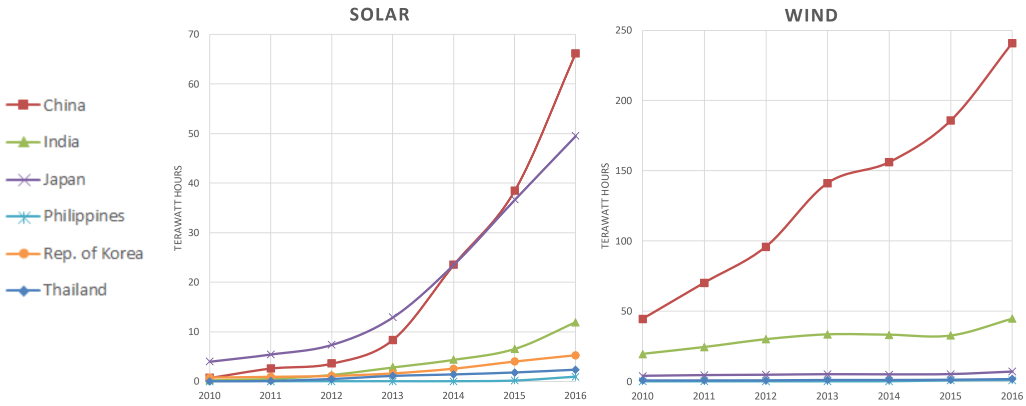

Figure 2.1: Solar and wind power generation in some Asian countries, 2010-2016
Source: BP 2017

2018). Policies promoting renewables have also been introduced by local governments. To cut spending on energy imports, Nagano, Japan introduced several reforms enabling community-based renewable applications to spread.

According to International Renewable Energy Agency (IRENA), Asia accounted for nearly two-thirds of the worldwide increase in renewable energy generating capacity in 2017, largely attributed to accelerated investment in China and India (IRENA 2018). As a result, aggregate capacity has doubled over the last five years, reaching 918 gigawatts (GW) in 2017 (IRENA 2018). Such growth is in line with ambitious targets set for clean energy, with India pursuing 175 GW by 2022 (IRENA 2017) and China aiming for at least 35 per cent of its electricity consumption being met by renewables by 2030 (IRENA 2018). With the cost of solar and wind installations projected to decline further in the foreseeable future, renewable energy is likely to supply a growing percentage of Asian energy for many years to come (NEO 2017).

Several challenges must be addressed to ensure the continued uptake and adoption of renewable energy across the region. The first challenge relates to infrastructure, involving the further improvement of transmission and distribution systems. The second is economic: governments need to adjust their policies to provide more fiscal and financial support for renewable energy, which includes the progressive divestment from fossil fuels. Lastly, behavioural barriers – such as the misconception that renewable energy contributes to grid inefficiency, rather than reliability – should also be confronted. Such issues need to be clearly considered in any policy initiative seeking to promote the use of renewable energy.

Coordination across and within agencies is also becoming more essential as governments aim for more multi-pollutant and multi-solution strategies. The kinds of strategies to address air pollution outlined in this chapter necessitate a rethinking of governance and decision-making processes, especially at the local and sectoral levels. In line with observations that governance is increasingly extending beyond the remit of central government (Bulkeley and Betsill 2005; Andersson and Ostrom 2008), many cities have been assigned responsibility for air pollution. While such decentralisation can pose challenges for local governments that lack the requisite capacity and resources, sub-national governments can also be an important source of bottom-up and entrepreneurial solutions.

Another potential source of support for these strategies is the participation of multiple stakeholders, including wider engagement with civil society. Such multi-stakeholder cooperation has been observed to not only improve the quality and durability of decision making (Martin and Shrington 1997; Fischer 2000; Beierle 2002; Reed 2007; Reed *et al.* 2008) but it can also assist with incorporating a wider range of ideas and perspectives into planning and programming (Dougill *et al.* 2006), by providing more complete information and anticipating potentially negative outcomes and countermeasures (Fischer 2000; Beierle 2002; Koontz and Thomas 2006; Newig 2007). Research also suggests that collaborative governance approaches can help in defusing confrontational relationships and identifying new ways for communities to work together (Stringer *et al.* 2006). Ultimately, participatory processes such as these show promise for enhancing the efficiency and effectiveness of local government (Richards *et al.* 2004; Reed 2008).

Another way that governments can build support for multi-sector and multi-solution strategies is by working directly with the public. In some cases, this will involve established institutional channels through which the general public can report pollution concerns. This is becoming easier due to technological changes; governments are increasingly turning to electronic tools and media to communicate air pollution information in ways that might enhance their accountability and strengthen regulatory compliance. In several countries, a shift is underway from relying on the internet and email to applications on smartphones and social media to provide timely pollution information – signalling a move from e-governance to mobile governance or m-governance. In organisations such as the European Environment Agency, electronic media are used to achieve two-way communication with clients by identifying information needs and ensuring that information is understood and taken up. Governments in Asia and the Pacific, however, have faced some constraints in disclosing air quality information and providing services that can improve air quality (Lu and Zheng 2013).

An additional trend that may enhance implementation capacities and compliance is citizen participation in air quality monitoring. Citizen scientists are increasingly using low-cost monitoring kits to measure air quality in their surroundings. This additional source of data can complement other reliable, accurate and timely monitoring data. For the time being, it may also provide useful scoping of the severity of pollution problems in fast growing medium- and small-sized cities that lack monitoring equipment.

Implications for industry.

As discussed, conventional sources of air pollution are likely to face increasing scrutiny over compliance with regulations. In response, there are growing opportunities for the adoption of familiar abatement technologies, such as flue gas desulfurisation, or turning to non-technical measures for reducing emissions, such as energy auditing that can induce energy-saving behavioural change. Many of these opportunities will not only improve the image of corporations but also save energy and money. There are also strategic market opportunities that will arise for more forward-thinking industries: for example, companies producing more efficient controls for remote-sensing technologies are likely to see their market grow. Many of these opportunities are not limited to conventional sources of air pollution. Emerging industries that can help control and reduce waste burning through improved waste management and improvements in managing manure are also expected as governments work relevant solutions into their air pollution strategies. And last but not least, the multiple benefits of clean energy hold promise to accelerate the transition to renewable energy that is already underway in many parts of Asia and the Pacific.

Policy implications.

It is incumbent on governments working to promote integrated approaches to air pollution to work across multiple sources and sectors. Doing so will entail designing packages of policies in such a way that they consider, *ex ante*, the potential impacts, benefits and trade-offs resulting from their implementation. In this regard, broad stakeholder participation will be key to ensuring that action and measures are not only inclusive and responsive, but also serve their intended purpose. In making this process more participatory, actual configurations of actors and the kinds of solutions are likely to differ. Guided by such an understanding, this chapter pointed to four of the 25 air pollution solutions outlined in *Air pollution in Asia and the Pacific: science-based solutions* (UNEP APCAP. 2019) to highlight a few examples that can help to achieve multiple benefits in the region.

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CHAPTER 3
Water Scarcity and Quality

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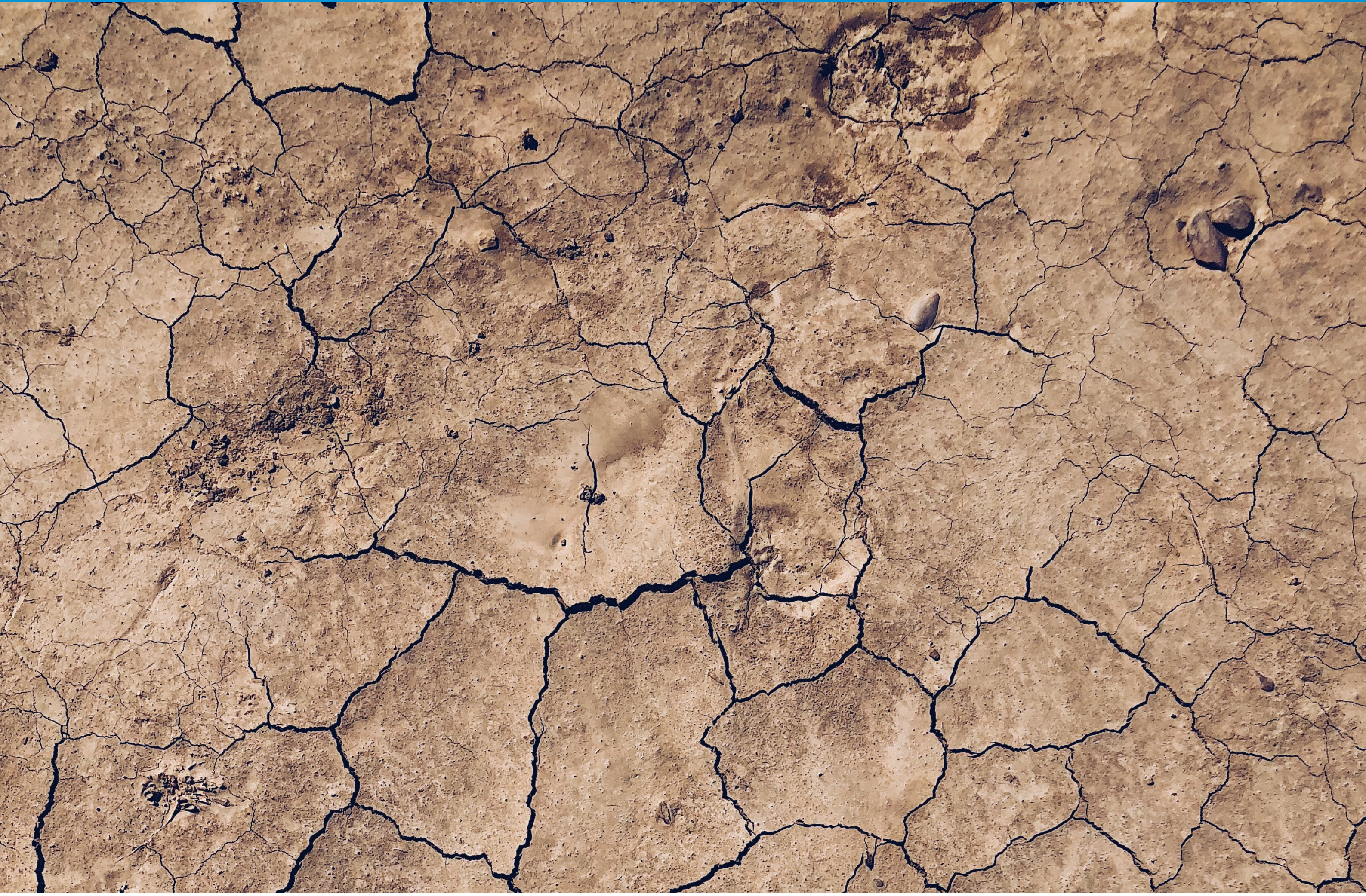

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KEY QUESTIONS

- What are the latest statistics and projections regarding water scarcity and quality?
- What are the main drivers of water scarcity – agriculture, overexploitation of groundwater, climate change, urbanisation, etc. – and how have these changed in the past decade or so?
- What are the main drivers of water pollution – industry, intensive livestock production, aquaculture, poor compliance and enforcement of laws and regulations, etc. – and how these have changed in recent years?
- What are the social and environmental implications of these changes? Are there largely hidden health impacts due to inadequate monitoring? To what extent can the current burden of disease be attributed to poor water quality?
- Which are the major regions and populations suffering from current and projected water scarcity?
- What are some of the key connections between water scarcity and water quality?
- What are some of the technological and management advances that are emerging to deal with the twin threats of water scarcity and water pollution, and are they likely to be sufficient?
- What are the implications for industry and how should industry provide a more robust response?
- What are the policy implications for governments in the Asia-Pacific region and for the international community?

Rapid changes in Asia and the Pacific are putting huge pressures on the region's water resources. The Asia-Pacific region, with more than 4.6 billion people in 2016, is home to nearly 60 per cent of the world population. The region is experiencing rapid population growth, urbanisation, industrialisation and significant changes in consumption patterns, including shifting diets towards highly water-intensive foods such as meat produced on industrial farms. The significant increase in water demand for food production has placed considerable stress on water infrastructure in the region. Asia has the highest annual water withdrawal of all the world regions, around 250 cubic kilometres (km^3)/year, owing to its geographic size, large population and increasing demand for irrigation.

The agricultural sector is the largest water consumer accounting for more than 70 per cent of the total demand in the region, followed by intensive industrial activities (Visvanathan 2018). The region has less than 30 per cent of the world's internal renewable freshwater resources, so per person, water availability in Asia is the lowest in the world. Parts of South Asia have quite low water availability and suffer from severe water scarcity. China, India and Pakistan may not have sufficient water to ensure food and energy security and develop under the current export-led economic growth model (China Water Risk 2018). In addition, Asia and the Pacific is one of the most disaster-prone regions if the world, and is also experiencing acute impacts from climate change including changes in evaporation and precipitation patterns, decreasing crop yields, significant temperature fluctuations and changes in water demand, water availability and water quality. Many countries are at high risk of climate-related disasters and sea-level rise, making their freshwater resources even more vulnerable.

Industrial agriculture and aquaculture play major roles in water pollution in the region, especially from intensive industrial livestock production, industrialised agriculture and aquaculture, as well as other related industrial activities. Effluent from these activities or farms is being disposed of in nearby surface water bodies and soil without undergoing any proper treatment. Large amounts of agrochemicals, fertiliser run-off, organic matter, drug residues and sediments are discharged directly into nearby water bodies, degrading water quality, as well as aquatic ecosystems, causing huge environmental, economic and health impacts and increased threats/risks to human and ecosystem health (UNEP 2016).

Of particular concern are hidden health impacts caused by non-conventional or emerging pollutants/contamination such as nutrients, pesticides, pharmaceutically active compounds and antibiotic-resistant bacteria. Already, up to 80 per cent of Asia's rivers have been deemed to be in poor health (Visvanathan 2018), and many are heavily polluted with up to three times the world average of human waste-derived bacteria, measured as faecal coliforms, coming primarily from untreated human sewage, livestock waste and industrial wastewater (Evans *et al.* 2012). In China, for instance, despite enormous progress over the past few years, of 972 national monitoring stations, 9.2 per cent showed surface water quality below Grade V in 2014, which means it is too polluted for any purpose, including irrigation (China.org.cn 2015). In Indonesia, the percentage of heavily polluted rivers, as defined by the Class II Water Quality Criteria in Government Regulation 82/2001, was already more than 60 per cent in 2008 and exceeded 70 per cent in 2016 (MOEJ and IGES 2018).

Water security in the region is now under severe threat both in terms of quantity and quality. Thus, to manage water resources more effectively and efficiently and ensure water security in the region, an insightful understanding of major drivers, pressures that lead to water scarcity and water quality degradation, state and trends, possible impacts on human health and the environment, and potential responses to prevent pollution and mitigate its impacts is required. This section investigates a number of key aspects of water quality and quantity, including:

i. main drivers, pressures and state of water scarcity, with a special focus on groundwater scarcity, and water pollution in the region, particularly due to intensive agricultural, aquaculture and industrial development;
ii. social, environmental and hidden health impacts/threats;
iii. potential technical, technological and managerial interventions for industry to adopt; and
iv. policy implications for governments in the Asia-Pacific region and for the international community (Figure 3.1).

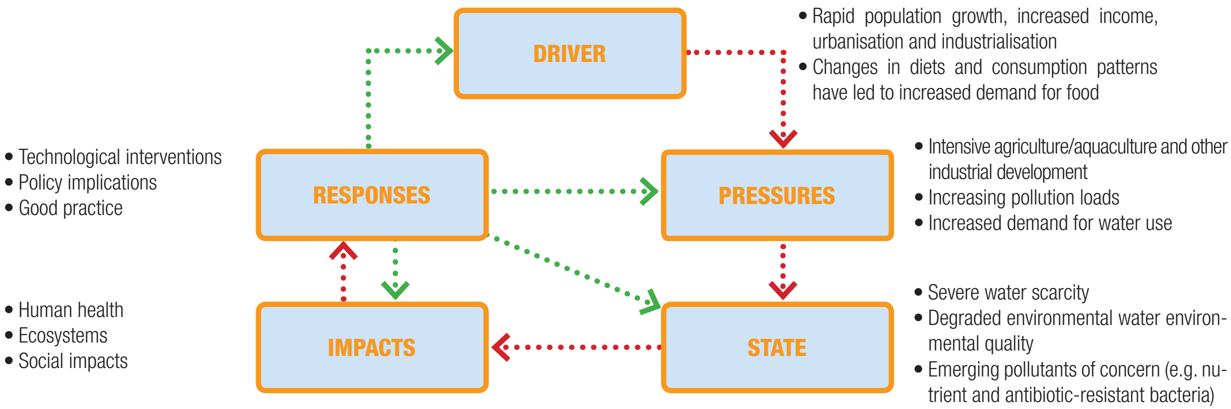


Figure 3.1: DPSIR framework for investigating impacts of emerging pollutants from industrial scale agricultural and aquaculture activities

There are multiple drivers of water scarcity and water pollution in the Asia-Pacific region. Rapid urbanisation, industrialisation, population growth, climate change, water-consumption behaviour and changes in lifestyles put enormous pressure on water resources and their ecosystems, ultimately resulting in severe degradation of water quality and water scarcity (Kumar *et al.* 2018; Mukate *et al.* 2017; Gosling and Arnell 2016). Water scarcity can be experienced

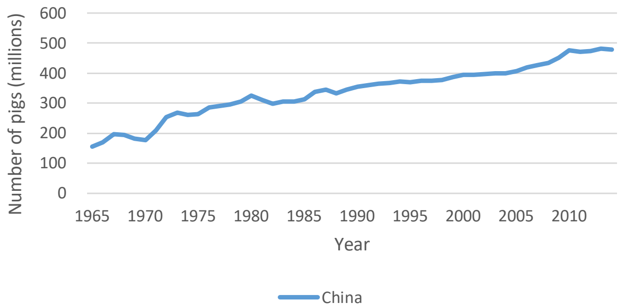
i. where water availability is too low to satisfy the minimum per person demand (often attributable to the geography and climate of the location); or
ii. where high water use is attributable to per person consumption or water withdrawals to meet industrial demands (Rockström *et al.* 2009).

Conserving groundwater is important in Asia as it plays a key role in sustaining the region's water needs (Lee *et al.* 2018). In large urban areas, the use of groundwater for industrial activities is usually greater than its domestic use. Groundwater-based irrigation contributes US$ 15–30 billion annually to the Asian economy (WWAP 2017) and seven of the world's 15 largest extractors of groundwater are in Asia and the Pacific (Margat and Van der Gun 2013).

Groundwater is under increasing threat. Groundwater withdrawals in Asia account for more than 70 per cent of the global usage, particularly in South and Southeast Asia, mainly due to rigorous industrial-scale agricultural and explosive population growth (FAO 2016). Groundwater is also a main source of supply for many cities and rural communities in the Asia-Pacific region. For example, 75 per cent of water supply in Bandung city, Indonesia, 100 per cent in Lahore in Pakistan, 92 per cent of the population in Vientiane in Lao PDR relies on groundwater; meanwhile, 60 per cent of the rural population in Cambodia and 76 per cent in Bangladesh depend on tube wells (WWAP 2015). In many urban areas in Asia and the Pacific, the industrial sector is also a major user of groundwater (Kataoka and Shivakoti 2013). Unfortunately, due to increasing use and over-extraction of groundwater, many problems have been observed in these areas, including land subsidence, lowering of the water table, contamination of groundwater and saline water intrusion into aquifers (WWAP 2015), putting groundwater under increasing threat across the region.

Groundwater abstraction is causing land subsidence and aquifer contamination. Land subsidence as a result of over-extraction of groundwater has been observed in a number of coastal Asian cities such as Bangkok, Thailand; Dhaka, Bangladesh; Ho Chi Minh city, Viet Nam; Jakarta, Indonesia; Kolkata, India; and Manila, Philippines. In eastern Bangkok, land subsidence rates of 10 centimetres (cm) per year or higher have been measured, and in several locations in Bandung, they have reached as high as 24 cm per year (WWAP 2015). Groundwater quality has also been affected in the region because of accumulation of natural and anthropogenic contaminants. In particular arsenic, fluoride and iron contaminants have reduced the usability of the region's aquifers.

Water pollution from industrial livestock production is a major concern. Livestock contributes up to 40 per cent of the global value of agricultural output and supports the livelihoods and ensures food security of almost 1.3 billion people (FAO 2018a). The Asia-Pacific region, particularly East, South, and Southeast Asia, has experienced dramatic increases in the production and consumption of livestock products over the last 30 years, due to a shift in dietary patterns driven by rapid income and economic growth, urbanisation and changes in lifestyles (FAO 2018b). Per person consumption of meat is very different from market to market but nevertheless increasing from year to year. Meat consumption is low in India, less than 10 kilograms/person/year, where many consumers are vegetarians, while Hong Kong, China has the highest per person combined meat and seafood consumption in the world in terms of volume. Per person meat consumption in Hong Kong in 2014 was around 100 kilograms/person/year; while in other parts of China and other countries, such as the Republic of Korea and Singapore, the volumes range from 45–80 kilograms/person/year (Friend 2018). Rapidly growing demand and technological innovation have been the most important factors behind the recent significant changes in the structure of the livestock sector, including a move from smallholder mixed farms to specialised large-scale, industrial scale, geographically-concentrated and commercially-oriented livestock production systems (Robinson *et al.* 2011). East and Southeast Asia have seen a radical transformation of the livestock sector, in particular to feed the growing demand for pig meat (Figure 3.2).



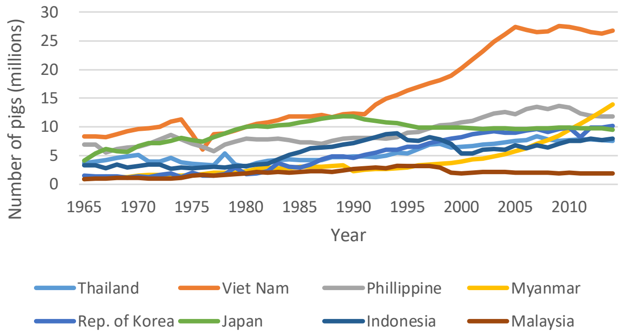


Figure 3.2: Changes in number of live pigs in China and some selected countries in Asia

Source: Kuyama 2017

The increasing concentration of livestock production is leading to new challenges and growing pressures on the management of waste. Pig waste contains nutrients, oxygen depleting substances and pathogens, drug residues, hormones and antibiotics, and poses a serious threat to surface waters and groundwater. The magnitude and frequency of harmful algal blooms is projected to increase as a consequence of eutrophication and climate change (O'Neil *et al.* 2012), leading to impaired human health and loss of biodiversity, acidification and ecosystem degradation (Menzi *et al.* 2010). For example, toxic blooms of cyanobacteria (blue-green algae) containing the microcystis genus have been founded around the world, posing a threat to drinking and recreational water, and contributing to a number of short and long-term health effects, including gastrointestinal symptoms, liver inflammation, liver failure leading to death, pneumonia, dermatitis, and even colorectal cancers (Cheung *et al.* 2013).

Intensive livestock production is polluting surface and groundwater. Intensive, industrialised production of livestock in the Asia-Pacific region, particularly pig production, consumes a large amount of water for drinking, cleaning and washing processes, which returns to the environment in the form of liquid manure, slurry and wastewater. The environmental risks associated with intensive livestock production are greatest in East and Southeast Asia because of the high concentration of animals, a lack of well-enforced regulatory safeguards, along with limited public awareness of the environmental impacts and the absence of appropriate measures for safe recycling of liquid manure to crops (Menzi *et al.* 2010). Consequently, waste from industrial piggery operations is the primary source of nutrient loading affecting waterways as well as groundwater aquifers in China, Thailand and Viet Nam, contributing from 14–72 per cent of nitrogen and 61–94 per cent of phosphorus accumulations (Reid *et al.* 2010).

Antibiotics are becoming an emerging contaminant of concern. The widespread use of antibiotics in human medicine and agriculture has fostered the emergence and spread of antibiotic-resistant organisms worldwide. The primary intention of antibiotic use in animal production is to improve animal health and productivity, consequently contributing to food security, food safety, animal welfare and sustainable food production. Due to long-term usage, water solubility and poor degradability, however, antibiotics are having long-term adverse effects on aquatic and terrestrial organisms (Milić *et al.* 2013). Van Boeckel *et al.* (2015) produced the first global map (228 countries) of antibiotic consumption in livestock and conservatively estimated the total consumption in 2010 at 63 151 tonnes. This study projected a 46 per cent likely increase in antimicrobial consumption in Asia alone by 2030 due to shifts in production systems. By 2030, antimicrobial consumption in Asia, with major contributors from China and India, is likely to be 51 851 tonnes representing 82 per cent of the 2010 global antimicrobial consumption in food animals. With the current rate of antibiotic usage in agriculture, annual deaths caused by drug resistant microbes could soar to 10 million by 2050 (Barber and Sutherland 2017). Agricultural pollutants from intensive livestock systems in the form of veterinary medicines such as antibiotics, vaccines and growth promoters or hormones, move from farms through water via leaching and runoff, as well as to ecosystems and drinking water through the application of manure and slurries to agricultural land. Zoonotic waterborne pathogens are another major concern (FAO and IWMI 2017a).

Antibiotic resistant microbes are being found everywhere. Prevalence, however, is highest in Asian developing countries because of poor public health infrastructure and governance. The recent rise in drug-resistant gram-negative bacilli results in a high occurrence of methicillin-resistant Staphylococcus aureus (MRSA), macrolide-resistant Streptococcus pneumoniae and multidrug-resistant enteric pathogens in Asia (Kang and Song 2013). Methicillin-resistant Staphylococcus aureus alone caused most common diseases to occur in Asian hospitals, namely pneumonia, surgical site infection, and bloodstream infections (Kang and Song 2013). For instance, more than 58 000 new-born babies lost their lives in India in 2013 because of bacterial infections that did not respond to antibiotics (Harris 2014). Noharm (2008) reported a significant correlation between non-human use of antimicrobial drugs and its human health consequences. Antibiotic resistant bacteria can be transmitted to humans through food, water, direct animal contact, etc. In addition, more than 75 per cent of the antibiotics used by livestock pass through the animal undigested and are excreted as resistant bacteria and genes. The major transmission route to humans of resistant bacteria is through animal faecal materials, used as crop fertiliser, contaminating both soil, water and crops (Sayre 2009). Antibiotic resistant organisms – bacteria, fungi, viruses and parasites – also inhibit the growth of other microbial colonies essential for both aquatic organisms and humans (Li *et al.* 2017). Apart of that, they also increase mortality rates, production losses, food insecurity, environmental degradation and significant impacts on overall global development, at an estimated cost of up to US$ 100 trillion worldwide by 2050 (Jasovsky *et al.* 2016).

Water pollution from industrial-scale aquaculture operations is also increasing. More than 75 per cent of the world's natural fisheries have already been fully or overexploited, leaving little room for increased harvests from wild stocks. Aquaculture therefore plays an increasingly important role in global food security as well as contributing to economic growth and livelihoods for hundreds of millions of people. Aquaculture has rapidly evolved as an industry for supplying aquatic products for the growing population through expansion and intensification. Per person apparent fish consumption increased from an average of 9.9 kilograms in the 1960s to 14.4 kilograms in the 1990s and 19.7 kilograms in 2013, with preliminary estimates for 2014 and 2015 pointing towards further growth beyond 20 kilograms (FAO 2016). World aquaculture production grew from 56 million tonnes in 2009 to 74 million in 2014. Inland aquaculture contributes nearly 62 per cent of total aquaculture production (FAO 2016). Asia accounted for nearly 90 per cent of the total aquaculture production in 2014. In 2014, the total Asian aquaculture production was 65 million tonnes, of which China alone produced 45 million tonnes (FAO 2016). Other Asian countries heavily reliant on aquaculture are Bangladesh, India, Indonesia, Thailand and Viet Nam.

There are multiple causes of environmental pollution from aquaculture in Asia. Due to a lack of legally binding procedures and inadequate management and monitoring frameworks, the aquaculture industry is developing in an unplanned manner. As a result, the number of small- and medium-sized aquaculture farms is growing rapidly, without consideration of potential environmental impacts (World Bank 2017). In developing countries, aquaculture farmers do not have sufficient knowledge and information to determine appropriate doses and how to use nutrients and antibiotics in an environmentally sound manner (Ali *et al.* 2016; Pham *et al.* 2015). Also a large proportion of Asia's small- and medium-scale aquaculture farms use lower-cost homemade feeds, which are of low quality and sometimes a biosecurity risk.

Major pollutants from aquaculture are nutrients and antibiotics. The rapid growth in aquaculture has brought higher levels of inputs including formulated feeds, agrochemicals, antibiotics and others as well as increased use of land and water. Most farmers in developing countries do not follow recommended amounts of feeds and dosages of agrochemicals, antibiotics or other chemicals, often believing that more is better. Residues of these excess inputs harms not only water and soil of the aquatic system but also increases risk for the surrounding environment and human health. Unused and dissolved feed as well as faeces can be a source of nutrients contaminating the aquaculture system and surrounding environment. In feed-based aquaculture, 20–40 per cent of nitrogen is in the protein of feeds, but a significant amount of nitrogen remains unused and is released to water and soil. Nitrogen use efficiency in China ranged from 11.7–27.7 per cent, whereas phosphorus use efficiency ranged from 8.7–21.2 per cent (Zhang *et al.* 2015). For every tonne of fish, aquaculture operations produce 42–66 kilograms of nitrogen waste and 7.2–10.5 kilograms of phosphorus waste (Strain and Hargrave 2005). Discharge of excess nitrogen and phosphorus into aquatic systems may lead to localised eutrophication problems and blue/green algal blooms.

As with land-based livestock, antibiotic use in aquaculture is of concern. Industrial aquaculture with high fish and farm densities creates an unhygienic and stressful environment, increasing the risk of bacterial infections in growing fish and shrimp. High doses of antibiotics are administered to prevent and control disease outbreaks. In Asia, various types of antibiotics are used including sulfonamides, potentiated sulfonamides, tetracyclines, penicillins, quinolones, nitrofurans, macrolides, aminoglycosides and chloramphenicol, with specific use varying by country. Tetracycline is the most common antibiotic in Asian countries with major aquaculture industries, with the Philippines and Thailand administering the highest number of antibiotics for preventing and controlling disease (Table 3.1).

About 75 per cent of the antibiotics applied with feed enters the aquatic environment through excretion of cultured species and leaching from uneaten medicated feed (Lalumera *et al.* 2004). A recent study reported that freshwater aquaculture is more contaminated with higher numbers and concentrations of antibiotics than brackish water aquaculture (Hossain *et al.* 2017) . The highest number of antibacterial resistant bacteria is reported in India followed by Indonesia, Bangladesh, Japan, and Thailand. Elevated concentrations of antibiotics increase pressure on bacterial populations, resulting in the prevalence of antibiotic resistant bacteria. Surprisingly, although only three antibiotics were reported to be used in Indian aquaculture, bacteria were isolated from the India aquaculture system, which were resistant to other antibiotics listed in Table 3.1. In most Asian developing countries antibiotics sales and use are either unregulated or weakly regulated, such as in India (Ganguly *et al.* 2011). Bhushan *et al.* (2016) reported that antibiotics were found across aquaculture systems of West Bengal of India including those not permitted or not labelled for use with fish.

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Table 3.1: Reported antibiotic use and presence of antibiotic resistant bacteria in aquaculture systems in Asia countries

	Bangladesh		China		India		Indonesia		Japan		Philippines		Rep. of Korea		Thailand		Viet Nam	
	Apply	ABR	Apply	ABR	Apply	ABR	Apply	ABR	Apply	ABR	Apply	ABR	Apply	ABR	Apply	ABR	Apply	ABR
Sulphonamides											✓				✓			
Potentiated sulphonamides		✓			✓						✓				✓		✓	✓
Tetracyclines	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Penicillins			✓			✓			✓	✓	✓		✓		✓		✓	
Quinolones	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Nitrofurans			✓			✓	✓				✓	✓			✓	✓		
Macrolides		✓	✓			✓	✓	✓	✓	✓	✓				✓	✓		
Aminoglycosides						✓	✓				✓		✓		✓			
Chloramphenicol	✓	✓	✓			✓	✓	✓		✓	✓				✓	✓	✓	✓

ABR: Antibiotic resistant bacteria

Sources: Binh et al. 2018; Bhushan et al. 2016; Bharathkumar and Abraham 2015; Visnuvinayagam et al. 2015; Sudha et al. 2014; Yuan et al. 2012; Sapkota et al. 2008

Nutrient pollution impacts human health, the environment and productive activities. Nutrient pollution from both agricultural and aquaculture activities has negative impacts on the environment, ecosystems, economies and particularly on human health. High levels of nitrates in water, for example, can cause methaemoglobinemia (blue-baby syndrome) which is a potentially fatal illness in infants. Annual environmental and social costs of water pollution caused by agriculture exceed billions of dollars (FAO and IWMI 2017). Examples of potential negative impacts on human health include:

i. increased burden of disease due to reduced drinking water quality;
ii. increased burden of disease due to reduced bathing water quality;
iii. high levels of nitrates in water causing methaemoglobinemia; and
iv. increased burden of disease due to unsafe food – contaminated fish and vegetables.

Potential impacts on the environment include:

i. decreased biodiversity;
ii. eutrophication and dead zones;
iii. visual impacts such as landscape degradation;
iv. bad odours, for example from manure;
v. diminished recreational opportunities; and
vi. increased greenhouse gas emissions.

Meanwhile, nutrient pollution also poses some potential impacts on productive activities such as reduced agricultural productivity; reduced market value of harvested crops, if pollution is acknowledged; reduced number of tourists in polluted areas; and reduced fish and shellfish catches (Hernández-Sancho *et al.* 2015).

Potential solutions are available for these water scarcity and quality problems. To overcome water scarcity and achieve sustainable water management, best practices include:

i. conjunctive use of surface and groundwater – storing excess water during the wet season for use in dry periods;
ii. full involvement and participation of local communities to reduce non-revenue water loss, reduce water wastage, install roof top water harvesting and enhance water recharge; and
iii. raise awareness and require responsibility of every sector of society to preserve water resources.

Improve nutrient management in agricultural and aquaculture operations. Water pollution in agriculture and aquaculture is complex and multidimensional, and effective management requires a comprehensive package of responses. Thus, there is a strong need for an integrated, holistic approach, which considers a wide range of relevant aspects, including regulations and policies, potential use of economic instruments, education and awareness-raising, cooperative agreements, research and innovation, as well as technological interventions.

Antibiotic resistant bacteria infection needs to be tackled at its source. Because of interwoven connections between humans, animals, ecosystems and the environment, a transdisciplinary approach is needed at the multinational scale to reduce the risk of antibiotic microbial infection. The core components of such action should include making people aware, through sharing information and capacity building; diligent monitoring and keeping inventories; minimising use of antibiotics; strictly implementing policy regulations and finally switching to more sustainable nutrient supplements for agriculture. Four core actions that will help fight these deadly infections are:

i. preventing infections and the spread of resistance;
ii. tracking resistant bacteria;
iii. improving the use of today's antibiotics; and
iv. promoting the development of new antibiotics and developing new diagnostic tests for resistant bacteria.

Establish a comprehensive mix of regulatory and other policy instruments. Recent analyses suggest that a combination of approaches – regulations, economic incentives such as emission or pollution charges, and information – works better than regulation alone (OECD 2008). For example, due to difficulty in reducing pollution from dispersed small-scale enterprises through regulatory measures, many local governments in China are shifting to economic incentives which motivate farmers to assume responsibility for reducing non-point source pollution (Shao 2010). In Japan, farmers are rewarded for reducing fertiliser applications, with the goal of improving water quality in lakes across the country. These lakes are important sources of drinking water, so the public is willing to pay farmers to ensure water quality is maintained at high levels (Ngoc-Bao *et al.* 2015). Policies addressing nutrient pollution from either industrial-scale agricultural or aquaculture production, should be part of an overarching national- or river-basin-scale water policy framework, with all pollutants and polluters considered together. Policies that encourage farmers to change their behaviour and facilitate the adoption of good practices, for example, through free advisory services, training and showcasing of good practice, are key to preventing pollution at its source.

Expand research and innovation, and information sharing. The issue of knowledge gaps and lack of scientific and reliable data concerning water pollution from industrial agriculture and aquaculture is quite common throughout Asia and the Pacific. In particular, the contributions of livestock and aquaculture to water pollution are not well known, especially in developing countries. Therefore, conducting national inventory analyses to quantify these contributions is essential, so that national governments can fully grasp the extent of the problem and develop meaningful and cost-effective responses. It is impossible to apply the polluter-pays principle if the source of pollution is unclear or unquantifiable. Therefore, promoting research and innovation in the field of water-quality monitoring and modelling is essential for obtaining a better understanding of pollutant pathways and the links between the causes and effects of pollution (FAO and IWMI 2017).

Industry needs to be held responsible for technological innovations that protect the environment. On-farm practices in intensive livestock and aquaculture operations are crucial for preventing pollution at its source. Manure management is one of the major concerns in livestock production, while unused and dissolved feeds, fish excretion and fish waste are considered the main source of nutrient pollution from aquaculture operations, creating an ideal environment for algal blooms in receiving water bodies.

In livestock production, manure needs to be properly stored, treated or safely reused. Effective techniques for manure treatment include composting and anaerobic fermentation, which can produce valuable organic fertilisers and soil conditioners. In addition to manure management, the use of feed additives, hormones and medicines in intensive and industrial livestock production should adhere to national standards and international guidelines. For off-farm practices, some simple technological interventions such as the construction of riparian buffer strips or constructed wetlands, could also be applied, cost-effectively reducing pollutant loads entering surface water bodies (FAO and IWMI 2017).

Aquaculture farms should adopt good management practices that protect the surrounding aquatic environment. Based on the carrying capacity of a water body, a suitable production biomass yield should be established aimed at:

i. avoiding excess feed by standardising feed inputs;
ii. using drugs correctly and avoiding prohibited ones;
iii. removing, treating and disposing of excessive nutrients in fishponds; and
iv. promoting integrated multitrophic aquaculture systems, in which the waste of one species serves as a food source for another (FAO and IWMI 2017).

Some other measures for mitigating pollution from aquaculture operations are presented in Table 3.2.

Table 3.2: Mitigation measures for aquaculture pollution

Polluting factors	Mitigation measures
Unplanned development of aquaculture industry	• Formulate aquaculture development policies, strategies and action plans including zoning for aquaculture farms • Control unauthorised aquaculture development by introducing licensing systems
Overuse of nutrients and antibiotics	• Formulate guidelines on nutrients and medicine use in aquaculture production • Regulate environmental monitoring • Strengthen extension services for fisheries • Provide training for farmers
Poor feed quality	• Provide training to the small- and medium-scale aquaculture farmers on good quality feed formulation

Implications for industry.

Where possible, an integrated aquaculture–agriculture system should be established, in which crops, vegetables, livestock and fish are managed collectively, thus increasing production stability, resource-use efficiency and environmental sustainability. Integrated farming ensures that waste from one enterprise becomes inputs to another, thereby helping to optimise the use of resources and reduce pollution (FAO and IWMI 2017).

Policy implications.

Industrial scale agriculture and aquaculture need to be treated like other industries, as a potentially serious source of environmental pollutants and hidden health impacts. The largely hidden nature of health and environmental impacts from these industries is not an adequate reason for the lack of policy, and technological innovation needed to address these issues of emerging concern.

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CHAPTER 4
Biodiversity and Industry

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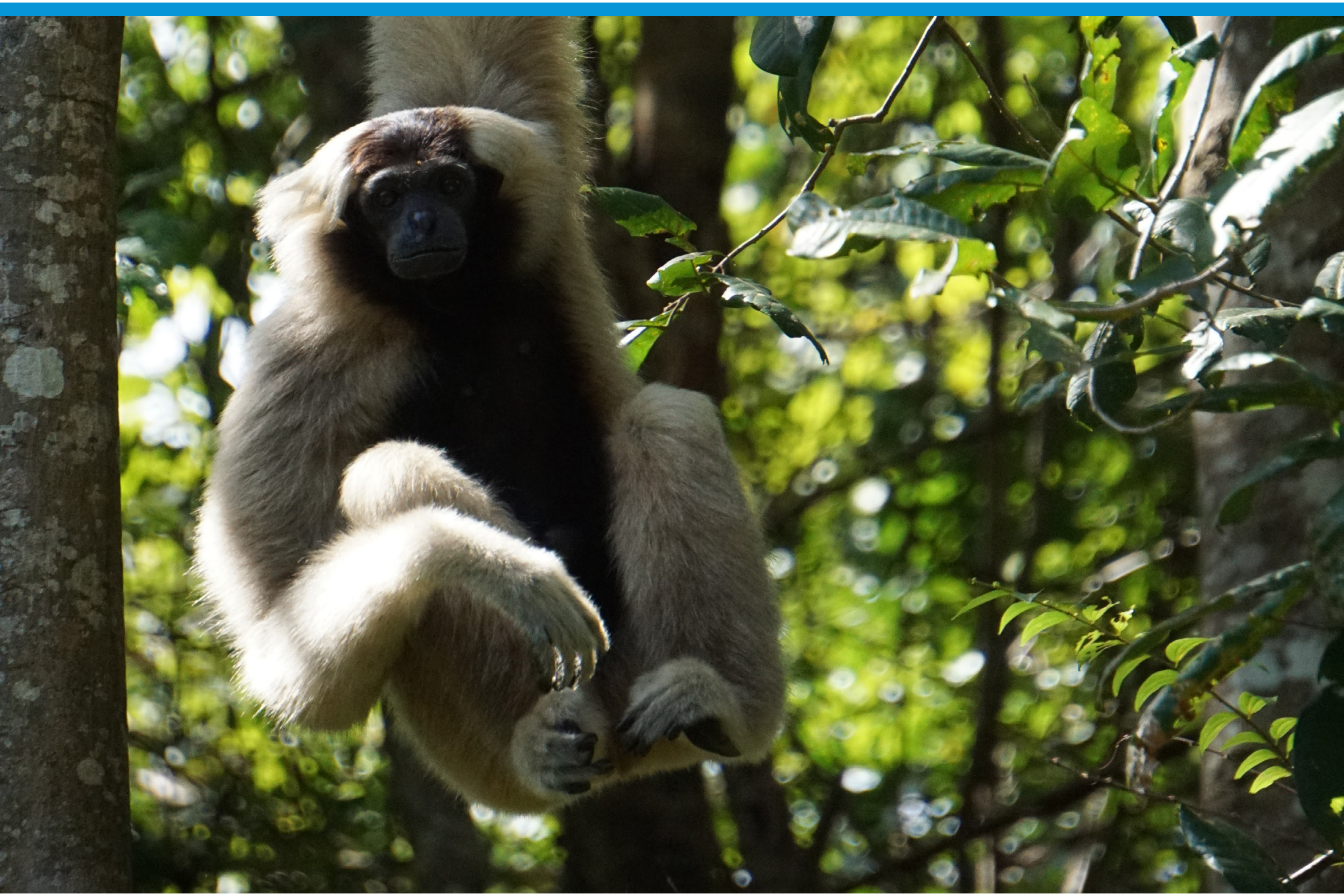

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KEY QUESTIONS

- As we are in the midst of the sixth mass extinction of species, what is driving biodiversity loss – deforestation, climate change, over-exploitation, land-use change, lost connection between humans and nature, poaching, hunting, etc. – and what is the prognosis for the Asia-Pacific region?
- What are the implications for humans if this biodiversity loss is not addressed?
- To what extent can in-situ and ex-situ protection – natural parks, gene banks, zoos, etc. – offset the inexorable species decline?
- New technological techniques such as gene editing, CRISPR (clustered regularly interspaced short palindromic repeats), artificial organisms, lab-grown meat, artificial photosynthesis, etc. have begun to emerge. What is their potential role in addressing biodiversity loss? What are some of the potential dangers as well as opportunities for these technologies?
- What are the implications for industry? Can we envisage a future where many of the ecosystem services provided by nature are replicated, and perhaps improved, by new start-up industries?
- What are the implications for governments? Should we begin to envisage a 50/50 world, where nature is assigned half the global area, or accept that industry will have to replace some of the ecosystem services being lost or diminished due to biodiversity loss?
- What is needed to ensure that industry is environmentally responsible, supporting rather than harming biodiversity?
- How can industrial production be linked with responsible consumption that reflects concerns for biodiversity?

Industry, in the context of this chapter, is mostly confined to the strict definition of the word: -"economic activity concerned with the processing of raw materials and manufacture of goods in factories" (OUP 2018). Industry has a major impact on nature and its biodiversity in Asia and the Pacific, as it does elsewhere in the world. Industry impacts biodiversity especially through the airborne, waterborne and soil-borne pollution that it produces, but also in other ways as elaborated upon in this chapter. At the same time, industry is reliant on biodiversity for goods and services. Many of these contributions from nature can be artificially replicated once they have been discovered and studied, and innovation is producing a growing selection of design solutions that may also benefit biodiversity. Nevertheless, on the current trajectory, it is unlikely that industry and technology will ever be able to replace all of nature's potential contributions before their full potential for industry is lost.

Industry is a driver of biodiversity loss. Globally, biodiversity is being lost very much faster than the rate that would be expected without human interference. The current rate of loss is believed to be on a par with the previous five extinctions experienced over the hundreds of millions of years of the life of our planet (Barnosky *et al.* 2011; Leakey and Lewin 1992).

In Asia, economies are growing rapidly overall, while China, India, Japan and the Republic of Korea alone already account for more than 40 per cent of all global R&D investment (Industrial Research Institute 2016). In the Asia-Pacific region the terrestrial, freshwater and marine environments have been severely degraded, and this decline is expected to continue given the current trajectory of development (Omar 2018). The value of the loss of biodiversity and ecosystem services under business-as-usual scenarios could be of the order of US$5 trillion per year (Omar 2018). The main direct drivers of this loss have been land degradation and land-use transformation, climate change, pollution, over-exploitation and invasive alien species (Bustamante *et al.* 2018). Industry is indirectly complicit in some of these, and directly complicit in others. Land-use change and land-cover change associated with rapid industrialisation have degraded land resources through pollution and soil erosion (Bustamante *et al.* 2018). Air pollution from the combustion of fossil fuels in industrial areas is responsible for forest damage and industrialisation has resulted in increased atmospheric nitrogen deposition, which threatens some marine environments (Bustamante *et al.* 2018). The major sources of water pollution, other than agriculture, are from industries involved in the production of metals, paper and pulp, textiles, food and beverages, and mining (Bustamante *et al.* 2018). Quarrying for cement threatens the survival of about 30 species in Southeast Asia alone (Clements *et al.* 2006), while eight out of 10 most polluted rivers in terms of plastic waste are in Asia (Lebreton *et al.* 2017). Yet, the scientific literature is brimming with a multitude of examples in medicine and in technology, of how society and industry *rely* on nature's phenomenal diversity for materials and ideas.

New threats are emerging. Unfortunately, it is not only established threats that endanger biodiversity – new ones are also emerging, such as industrial-scale manufacturing and use of nanomaterials. Some nanomaterials have the potential for bioaccumulation in plants and microorganisms as well as through the food chain (IPBES 2018; CDC-NIOSH 2014; Kwazo *et al.* 2014; Scrinis 2006). Biotechnology is another modern phenomenon that is widely considered to threaten biodiversity. Although well established, advances in this field are rapid, further fuelling concern. And yet its proponents suggest that it may offer the best solutions for some of biodiversity's greatest challenges, as discussed later.

Our reliance on biodiversity is not diminishing. Biodiversity consists of ecosystem diversity, species diversity and genetic diversity. Ecosystems, and the species and genes that constitute their living components, provide a variety of services to humankind. These are commonly referred to as ecosystem services or, more recently, nature's contributions to people (IPBES 2018). These services, or contributions, include raw materials such as the processed timber used for building and the raw timber used to produce heat and energy in many of the developing parts of the region. They also include the provision and flow regulation of water that is required by all industries in their manufacturing processes and the plants that help to purify water polluted by industry. It is expected that water withdrawals in the region will increase by 55 per cent due to growing needs for domestic water, food production, manufacturing and thermal electricity generation (IPBES 2018; ADB 2016).

Medical advances rely on biodiversity. Biodiversity includes the genetic resources that constantly fuel the pharmaceutical industry's quest for more and better medicines, with an estimated minimum of 70 per cent of new small-molecule drugs introduced worldwide from about 1982 to 2007 originating from, or inspired by, a natural source (WWF 2018; Newman and Cragg 2007).

Another interesting emerging example of mimicking nature is artificial photosynthesis. Traditional photosynthesis is the process by which plants convert carbon dioxide from the air into carbohydrates and oxygen, in the presence of water and sunlight. Artificial photosynthesis is a synthetic process that replicates this, typically to store energy from sunlight in fuel – a new method with promising potential (Fukuzumi *et al.* 2018; El-Khouly *et al.* 2017).

Mobilising industry for sustainability transitions is an urgent challenge. Sustainability transitions are widely recognised as essential to address biodiversity loss and to the achievement of the SDGs. They have been defined as fundamental changes in socio-technical systems towards sustainability (Bijker *et al.* 1987). As socio-technical systems are the configurations of hardware and software, and social, psychological, political, policy and legal systems that underpin economies (Whitworth and de Moor 2009), industry clearly has a critical role to play in sustainability transitions.

Technological transitions are extremely complex. Studies of historical technological transitions, for example from sailing ships to steamships, have found that movement towards the widespread acceptance of innovative technologies requires more than just the technology; it also requires changes in user practices, regulation, industrial networks, infrastructure and culture (Geels 2002). To support sustainability transitions, policy mixes that destabilise established unsustainable regimes and promote radical green niches as well as their mainstreaming are needed (Smith *et al.* 2010). Opportunities, incentives, controls, support mechanisms and cross-sectoral policy coordination are all important for mobilising industry for sustainability transitions.

Responsible consumption and production can be linked through sustainability certification. A wide variety of voluntary schemes certify the sustainability of industrial processes. These can be found in the forestry sector, where they have been strongly promoted as a way of reducing the harm done by industrial-scale logging in natural forests on biodiversity and ecosystem services. Some schemes require the identification and preservation of areas with high conservation values, while allowing reduced-impact logging in other areas. There is evidence that such schemes can contribute to improved biodiversity outcomes (Dasgupta 2017). When these schemes include product labelling, they link responsible consumption with production with (SDG 12: Responsible consumption and production) by enabling buyers to identify products from sustainable sources.

While voluntary sustainability-certification schemes have been around for several decades, their uptake has been slow, especially in developing countries. This is evident in the forestry sector, with Africa, Latin America, Asia and Oceania accounting for only 15 per cent of the total global certified forest area (UNECE/FAO 2018). The reasons for this slow uptake include lack of attractive price premiums to offset the high costs of certification (UNECE/FAO 2009) and continued existence and growth of new markets that do not demand sustainable extraction (Scheyvens *et al.* 2015).

New technology may enhance sustainability certification. For certification to be instrumental in a sustainability transition towards responsible consumption and production, rethinking of technical elements and the concept itself are required. In terms of technical improvements, there may be potential for blockchain technology, made famous by the cryptocurrency Bitcoin, to replace the complex chain-of-custody processes that certification schemes use to control and document the movement of materials (Figorilli *et al.* 2018). As a blockchain is a decentralised ledger, anyone can access transaction records. This opens up the tracking process of materials and products to scrutiny and does away with the need for a third-party monitor. Government support would also help certification realise its full potential. Certification can help governments achieve their own objectives for biodiversity and economic sustainability in specific sectors, so there are good reasons for governments to promote certification. They can explore the possibility of various incentives for companies to acquire certification, such as tax exemptions and public procurement policies for sustainable materials and products.

Wastes and cultivated building materials can be used in architectural applications. In the Asia-Pacific region, waste generation is increasing and poor waste management has resulted in harm to biodiversity and degradation of ecosystems (Davies *et al.* 2018). At the same time, the region is experiencing growing demand for housing and other buildings as a result of population growth, urbanisation and rising affluence (UNEP 2016). Using waste residues as inputs for building materials could both help mitigate the harm caused to biodiversity by waste and address the housing problem.

Biomass residues are a potential source of new building materials. In particular, residues from the harvesting of cereal crops and agro-industrial processes are a huge potential source of fibres that could be used to produce environmentally-friendly building materials (Hebel and Heisel 2017). This notion has been supported by various research into bio-composites that have led to new environmentally superior, high quality building materials. With funding from the European Regional Development Fund, for example, a team of materials scientists, architects, product designers, manufacturing technicians, and environmental experts collaborated to develop a new material for façade cladding using raw agro-fibres. Agro-fibres from barley, maize, oats, rice, rye and wheat straw can be used and contribute up to 90 per cent to the final material by weight (Dahy and Knippers 2017). This project developed a type of bioplastic granule that can be extruded into sheets and further processed. The sheets were used to develop a flexible, recyclable and compostable high-density fibreboard for use in buildings. Another example is the structural composite panel ECOR manufactured by Noble Environmental Technologies using forest waste, agricultural fibres, bovine process fibre, and paper and cardboard waste. ECOR has been commercialised and used in a broad spectrum of industries and applications by global brands wanting to promote their environmental credentials. Applications include wide format printing, furniture and fixtures, and building interiors (https://ecorglobal.com). Production of such bio-composites does not rely heavily on petroleum-based components and additives, which means they can contribute to a healthy living environment, at the same time as reducing harmful waste from farming, forestry, manufacturing and building demolition.

There is also a strong argument for the cultivation of building materials. This means not just the growing of trees, but also new ideas such as purpose-built breeding farms, using micro-organisms that until recently had not been considered useful for the building industry (Hebel and Heisel 2017). Using recycled agricultural fibres and cultivated building materials would help the construction sector move away from a system that relies on the unsustainable mining of materials, which harms biodiversity, to a closed loop system using renewable and recycled materials ((Hebel and Heisel 2017). Further research into the use of recycled agricultural fibres and cultivated building material is likely to be most productive when conducted by teams of scientists from various disciplines, product developers and practitioners. In addition to new product breakthroughs, modification of the existing industrial setting to accept new materials and construction methods will be needed for bio-composites to contribute to a sustainability transition in the building industry.

Synthetic biology is also developing rapidly. The rapid advancement of biotechnology and its potential risks to biodiversity led governments to adopt the Cartagena Protocol on Biosafety to the Convention on Biological Diversity (CBD 2000), which aims to ensure the safe handling, transport and use of living modified organisms (LMOs) resulting from modern biotechnology that may have adverse effects on biological diversity, also taking into account risks to human health. More recently, advances in gene editing and CRISPR technology have revived these concerns, with successive decisions on the topic of synthetic biology featuring at the three most recent meetings of the Conference of the Parties to the Convention on Biological Diversity (CBD 2014; 2016; 2018).

Synthetic biology both offers great hope and raises great concern. Synthetic biology is defined as “a further development and new dimension of modern biotechnology that combines science, technology and engineering to facilitate and accelerate the understanding, design, redesign, manufacture and/or modification of genetic materials, living organisms and biological systems” (CBD 2016). It involves the alteration of natural genomes with extremely precise editing (Piaggio *et al.* 2017). On the one hand, this creates the possibility of natural organisms being “tweaked …to allow for patent monopolies beyond the reach of state sovereignty or of indigenous peoples” (ETC Group 2010). On the other, it holds the potential to resolve some persistent conservation problems, such as invasive species. Certain species of rodents, for example, have been responsible for the extinction of hundreds of species of birds, especially on islands where fauna is more susceptible to aggressive introduced species (Blackburn *et al.* 2004). Current methods are limited in their effectiveness and have proven side effects, so work is being conducted to explore the feasibility of creating mice with a gene from the Y chromosome inserted onto chromosome 17 (autosome) that results in the production of only male offspring – thereby rendering the island population eventually incapable of reproducing (Piaggio *et al.* 2017). An even more controversial application involves de-extinction, bringing back animals that no longer exist by editing the genome of similar extant species to incorporate genetic code from the extinct species (Piaggio *et al.* 2017; Redford *et al.* 2014; Sutherland *et al.* 2014).

Lab-grown meat is a potential alternative to livestock rearing. Lab-grown meat is an example of how biodiversity provides the seeds of a solution to a problem that threatens biodiversity itself. Meat production, especially through large-scale industrial agriculture driven by the increasing global demand for meat, has a major impact on biodiversity simply through the amount of land it requires. Globally, the land area taken up by the pasture required by livestock is double that of the area taken up by crops grown directly for human consumption. In addition, livestock consume around a third of the crops harvested specifically as feed (Alexander *et al.* 2017; Machovina *et al.* 2015; FAO 2006). Land-use change, and other aspects of livestock production also contribute significantly to the emission of greenhouse gases (FAO 2006). These considerations make meat consumption a major environmental concern as well as an ethical and health-related one. One innovative solution is the production of meat in the laboratory using only cells from the original animal. This approach requires significant reduction of land use (Stephens and Ruivenkamp 2016; Tuomisto and de Mattos 2011). The cost of lab-grown meat is still prohibitive at about US$ 600 for a hamburger. This is, however, down from a somewhat more expensive US$ 340 000 only five years ago (Stephens and Ruivenkamp 2016) and is expected to reach US$ 5 in the foreseeable future. Another challenge is unsurprising conservatism of cultural norms in accepting such an unusual alternative, but this is expected to change gradually. A final challenge concerns the climate impacts of lab-grown meat. The new technology may offer a significant improvement over traditional meat production only if it is accompanied by sustainable forms of energy production.

Implications for industry.

While the externalisation of costs benefits the profit margins of industry in the short term, it poses a risk to industry – and society as a whole – over the long term by reducing the potential to use biodiversity for R&D. Biodiversity and ecosystem services are being lost at an alarming rate. Without transformational changes in industrial production systems and consumption patterns, the basic functioning of vulnerable ecosystems will continue to break down. The likelihood of exceeding a 1.5ºC increase in global temperature above pre-industrial levels (IPCC 2018) is a high-profile and macro-scale example of the serious consequences of transgressing planetary boundaries.

Policy implications.

With 60 per cent of the world's population, 52 per cent of the global poor and a rate of economic growth double that of the global average, Asia and the Pacific's significance in the planet's future is not to be underestimated. Technological advances and progress in economic development ignoring consideration of biodiversity and ecosystem conservation is unlikely to lead to improved human well-being and a good quality of life (IPBES 2018). Policymakers and industry will need to work together towards a more desirable scenario of progress. While industry is a driver of both biodiversity loss and of innovation that may contribute to conserving biodiversity, biodiversity is a driver of industrial innovation and a resource base for industry. A relationship of such crucial mutual interdependence, and such consequential risks and benefits, is deserving of special attention.

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SECTION 2

Emerging Pollutants from Industry

CHAPTER 5
Electrical and Electronic Waste

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KEY QUESTIONS

- How quickly has waste electrical and electronic equipment (WEEE) emerged as a major environmental problem in the Asia-Pacific region? How is WEEE handled in the region and what are the environmental problems emanating from these approaches?
- What are the projections for future volumes of WEEE and is the recycling industry capable of dealing with this volume in an environmentally sound manner?
- What are some of the technological and organisational alternatives to the current approach, such as eco-design, repairable products, further miniaturisation, regional processing centres, take-back requirements, new materials, etc.?
- What are the implications for industry? Should industry open new lines of business to refurbish old electronic equipment? Should industry change its design parameters to include end-of-life considerations?
- What are the implications for governments? Is banning the importation of e-waste a sufficient response? What else needs to be done?

Definition and classification of electrical and electronic waste. Waste electrical and electronic equipment (WEEE) can be classified into six categories:

- temperature exchange equipment: refrigerators, freezers, air conditioners and heat pumps;
- screens and monitors: televisions, monitors, laptops, notebooks and tablets;
- light bulbs: fluorescent, compact fluorescent, high intensity discharge and light-emitting diode (LED) bulbs;
- large equipment: washing machines, clothes dryers, dish-washing machines, electric stoves, large printers, copying equipment and photovoltaic panels;
- small equipment: vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radios, video cameras, electrical and electronic toys, small electrical and electronic tools, small medical devices, small monitoring and control instruments; and
- Small information technology (IT) and telecommunications equipment: mobile phones, global positioning systems (GPS), pocket calculators, routers, personal computers and printers, and telephones (Baldé *et al.* 2015).

Rapid industrialisation and middle-class population growth in Asia and the Pacific have led to increasing consumption of electrical and electronic equipment (EEE) and makes EEE life shorter. As industrialisation of Asia and the Pacific has sped up, there has been simultaneous growth of the middle-class population, which often demands the latest products before older ones have reached the end of their useful lives. The Asia-Pacific region is the world's largest manufacturer of, and market for, EEE. For example, mobile phone subscribers in India increased from 310 million in 2001 to 1.1 billion in 2016 (Herat 2018), nearly 4 times that of United States today, second only to China, which had 1.57 billion subscribers in 2018 (MIIT2018). In 2012, Asia consumed 26.69 million tonnes (Mt) of EEE, accounting for 50 per cent of the global market (Honda *et al.* 2016). The fast development of information and communication technology (ICT) has also led to a rapid increase in EEE consumption and shorter life of products. The average EEE life span has been estimated as 4.5-7.5 years, of which cellphones, smartphones and tablets have the shortest, just 4–5 years (Table 5.1).

Table 5.1: Estimated lifespan of EEE, 2014

Items	Average Life (years)
Flat panel TV	7.4
Digital camera	6.5
DVD player or recorder	6.0
Desktop computer	5.9
Blu-ray player	5.8
Video game console	5.7
Laptop/notebook	5.5
Tablet	5.1
Cellphone (not smartphone)	4.7
Smartphone	4.6

Source: Kumar et al. (2017)

Asia is the world's biggest WEEE generating region. In general, WEEE generation is higher in those countries with higher GDP and income per person (Kumar *et al.* 2017). Global WEEE generation was around 41.8 Mt in 2014, or 5.8 kilograms per person, increasing to 44.7 Mt in 2016, or 6.1 kilograms per person. This volume is projected to reach 50 Mt in 2018 and 52.2 Mt, or 6.8 kilograms per person, by 2021 (Baldé *et al.* 2017; Baldé *et al.* 2015) (Figure 5.1). Of this total, the Asia generated the largest amount of WEEE, 18.2 Mt, accounting for 40.7 per cent of the global amount, but less e-waste per capita – 4.2 kilograms per person in 2016.

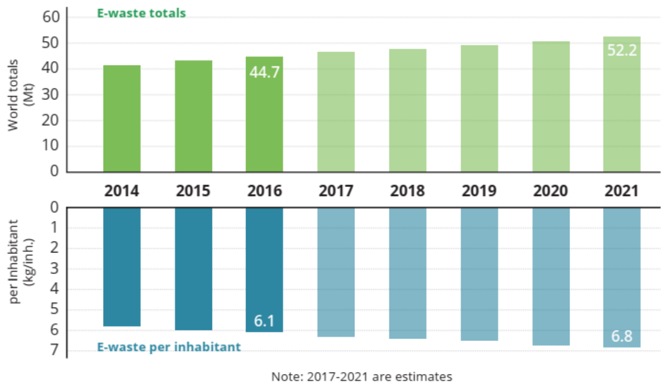


Figure 5.1: Global generation of electrical and electronic waste, 2014-2021

Source: Baldé et al. (2017)

China, Japan and India generate the largest amounts of WEEE in Asia and the Pacific, as these nations manufacture the most electronic products, with absolute volumes of 7.2 Mt, 2.1 Mt and 1.9 Mt respectively in 2016 (Baldé *et al.* 2017; Modak *et al.* 2017). In the Pacific region, generated WEEE volume was 0.7 Mt in 2016, of which Australia was the largest generator with 0.57 Mt, equivalent to 23.6 kilograms per person (Table 5.2). There is an increasing WEEE generation trend in the Asia-Pacific region. In East and Southeast Asia, the amount generated increased by 63 per cent between 2010 and 2015 and in China the WEEE volume more than doubled between 2010 and 2015, reaching 6.7 Mt (Honda *et al.* 2016) and is projected to increase to 15.5 Mt and 28.4 Mt in 2020 and 2030, respectively (Zeng *et al.* 2015).

Table 5.2: Electrical and electronic waste generation in selected Asia and Pacific countries

Country	WEEE generated in 2016 (kilogram per person)	WEEE generated in 2016 (thousand tonnes)
China	5.2	7,211
Japan	16.9	2,139
India	1.5	1,975

Country	WEEE generated in 2016 (kilogram per person)	WEEE generated in 2016 (thousand tonnes)
Indonesia	4.9	1,274
Republic of Korea	13.1	665
Iran	7.8	630
Australia	23.6	574
Thailand	7.4	507
Pakistan	1.6	301
Philippines	2.8	290
Malaysia	8.8	280
Iraq	6.1	221
Bangladesh	0.9	142
Viet Nam	1.5	141
Singapore	17.9	100
New Zealand	20.1	95

Source: Baldé et al. (2017)

End-of-life solar photovoltaic (PV) panels and electric vehicle (EV) batteries will be emerging WEEE issues in the next two decades. To combat climate change and air pollution, the world is witnessing rapid development of PV panels and EVs. According to the International Renewable Energy Agency (IRENA), installed solar PV capacity was 222 GW in 2015 and will reach 4 500 GW by 2050 (Figure 5.2), of which three of top five countries are in Asia, specifically China, 1 731 GW; India, 600 GW; and Japan, 350 GW. With the development of the PV market, the waste from decommissioned PV will also increase, with a decreasing time lag as ever cheaper panels dominate the market. Cumulative global PV waste was estimated at about 43 500–250 000 tonnes in 2016, around 0.1–0.6 per cent of the cumulative mass of installed panels, 4 Mt. Although a small part of WEEE at present, with average panel lifetimes of 30 years and declining, PV waste will become an emerging issue from the early 2030s. It is forecast that the cumulative amount of PV waste will be 1.7–8 Mt in 2030, 60–78 Mt in 2050 (Figure 5.2). By the end of 2050, cumulative volumes of PV waste in China, Japan and India will be 20.0, 7.5 and 7.5 Mt respectively (IRENA and IEA-PVPS 2016) and thus it will be a pressing issue in the region.

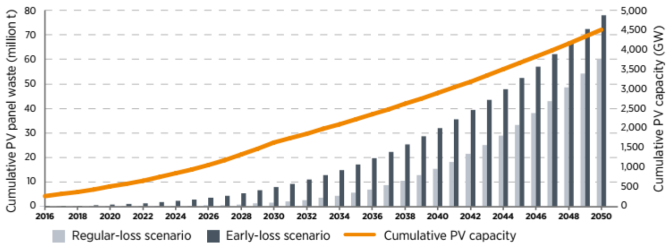
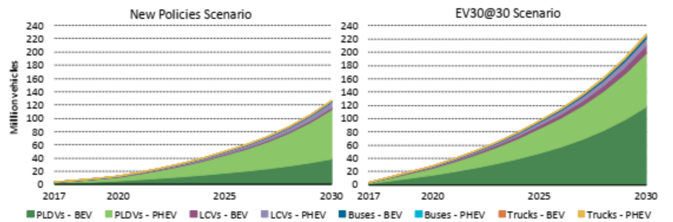


Figure 5.2: Cumulative photovoltic panel capacity and waste 2016-2050

Source: IRENA and IEA-PVPS 2016

The number of EVs is increasing globally, so EV waste batteries will too. According to the International Energy Agency (IEA), the global EV stock increased from around 0.4 million in 2013 to more than 3.0 million in 2017. In 2016, the global sales reached 750 000 and it is forecast to rise to 24.4 million by 2030, mostly in China and the United States (Drabik and Rizos 2018). As the EV stock number is increasing very fast, reaching around 120-220 million vehicles in 2030 (Figure 5.3), EV battery waste is also increasing fast. It is estimated that, by 2020, about 250 000 tons of batteries from EVs will have to be disposed of or recycled (IEA 2018). However, recycling technologies for these batteries, especially of lithium-ion batteries, are still not adequately developed and this will become a big issue in near future (Zhang *et al.* 2018).



Notes: PLDVs = passenger light duty vehicles; LCVs = light commercial vehicles; BEVs = battery electric vehicles; PHEV = plug-in hybrid electric vehicles.

Figure 5.3: Global electric vehicle stock in two scenarios 2017-2030

Source: IEA 2018

The Asia-Pacific region is one of the two key WEEE destinations/treatment centres globally. Due to cheap labour, lack of regulation and poor enforcement, 80 per cent of WEEE generated in the developed world ends up in the Asia-Pacific region and Africa (Alam and Carandang 2016). In Asia, Japan and the Republic of Korea are WEEE exporting countries while other countries such as Cambodia, China, India, Indonesia, Malaysia, Philippines, Thailand and Viet Nam, are the destinations of e-waste exports, which are often illegally disguised as imports of raw materials, materials for reconditioning/reuse, for charity or scrap (Tran and Salhofer 2018). These countries are beginning to respond to this issue.

Since the end of 2018, the importation of of electrical appliance hardware scrap for the recovery of iron, steel, copper and aluminium (mainly including waste electric motors and waste cables) has been banned in China (WRRA 2018). Before that, India has also banned import of WEEE in 2015 (Goel 2015). This policy may drive the traditional exporters, such as the United States, European Union, Japan and Australia, to enhance their own domestic recycling capacities and activities. Neighbouring countries such as Cambodia, Malaysia, Thailand and Viet Nam face their own challenge of combating illegal waste transboundary movement due to the potential changes in destinations of such exports.

Electrical and electronic waste can have toxic impacts on human health. Electrical and electronic waste contains various toxic and hazardous substances, including plasticizers, lead, mercury, cadmium and arsenic, which pose serious hazards to human health. The informal sector's recycling practices using primitive technologies magnify health risks, especially to those involved in treatment processes. The release of heavy metals from WEEE processing causes acute and chronic effects including cancer, respiratory irritation, reproductive problems, pulmonary, cardiovascular and urinary infection/diseases (Awasthi *et al.* 2018; Vats and Singh 2014; McAllister 2013). For example, several years ago, in China, studies at e-waste informal recycling sites in Taizhou, Guiyu and Qingyuan showed that residents are potentially faced with a higher daily intake of pollutants than residents in the studies' control areas. Pollutants from WEEE recycling including polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyl (PCBs), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and heavy metals have been detected in the tissue samples of residents (Song and Li 2014a; 2014b). In Viet Nam, all children examined in Dong Mai lead recycling village had high blood lead levels and needed urgent remediation (Daniel *et al.* 2015). It should be noted that knowledge about the toxic nature of WEEE and its processing is still, at best, limited (Ikhlayel 2018).

Electrical and electronic waste processing also has toxic impacts on the environment. Toxic emissions from WEEE and its treatment mix with uncontaminated soil and air thereby having harmful effects on entire biota, either directly or indirectly. Direct impacts include the release of acids and toxic compounds including heavy metals and carcinogenic chemicals, while indirect effects include the bio-magnification of heavy metals (Sankhla *et al.* 2016).

Resource recovery provides an incentive for effective recycling of WEEE. There is a number of valuable materials and precious metals in WEEE including iron, copper, aluminium, plastics, gold, silver, platinum and palladium, and in many cases their concentrations in WEEE are much higher than in mine ore (Table 5.2). For example, in 2014, the amount of gold in e-waste was around 300 tonnes, equivalent to 11 per cent of the gold mined in 2013 (Herat 2018). The total value of all raw materials in WEEE which have not been totally extracted and reused in the economy in 2016 was estimated at approximately EUR 55 billion (around US$ 60 billion) (Baldé *et al.* 2017). Material recovery from PV panels could cumulatively reach to US$ 450 million (in 2016 terms) by 2030, equivalent to the amount of raw materials currently needed for production of 60 per cent of new PV panels; by 2050 this cumulative value could be as high as of US$ 15 billion (IRENA and IEA-PVPS 2016). Recycling WEEE could provide a ready source of scarce natural elements such as gallium and indium, as well as saving considerable amounts of energy when compared to extracting virgin materials (Kumar *et al.* 2017), but today, poor management of WEEE and low recovery rates of materials causes the loss of natural resources, including precious metals (Maheshwari *et al.* 2013).

Table 5.3: Metal concentrations in electronics and ore

Product	Copper (% by weight)	Silver (ppm)	Gold (ppm)	Palladium (ppm)
Television board	10	280	20	10
Personal computer board	20	1 000	250	110
Mobile phone	13	3 500	340	130
Portable audio scrap	21	150	10	4
DVD player scrap	5	115	15	4
Average electronics	13.8	1 009	127	51.6
Ore/mine	0.6	215.5	1.01	2.7

Note: ppm = parts per million

Source: Kumar et al. 2017

There is a lack of statistics on WEEE. Globally, only 8.9 Mt of WEEE has been documented as collected and recycled, which corresponds to about 20 per cent of the amount generated. The remainder, 80 per cent or 35.8 Mt, has not been documented and what has happened to it is unknown, but is likely to have been traded, dumped or recycled in unsafe conditions. Only 41 countries worldwide have official WEEE statistics, in another 16 WEEE quantities have been researched and estimated, while in the rest, WEEE is just managed as general waste (Baldé *et al.* 2017). In many developing countries in the Asia-Pacific region, there is a large gap between statistical data and facts due to illegal imports (Tran and Salhofer 2018). Furthermore, the WEEE inventory is poor or does not exist in many countries as they lack standardised methods for estimating its volumes (Ikhlayel 2018), which would help build a WEEE database.

Treatment of WEEE is comparatively advanced in developed countries while the informal recycling sector plays a key role and causes environmental pollution in developing countries. The level of WEEE management varies among Asia-Pacific countries which can be classified into four groups. A few countries such as Japan and the Republic of Korea have advanced WEEE management systems, some, such as Singapore, have voluntary initiatives; others, Malaysia, Philippines and Viet Nam, are in transition; while such countries as Cambodia, Indonesia and Thailand have informal initiatives (Honda *et al.* 2016).

Management of WEEE includes collection, recycling and disposal. Collection of WEEE is usually implemented through official take-back systems in developed countries and by informal collectors in developing countries. In developed countries, such as Japan and the Republic of Korea, official take-back systems are in place through curbside collection, municipal collection points, retailers or commercial pick-up services and WEEE is then transported to formal, high-technology processing centres (Kumar *et al.* 2017). In 2016, Japan, for example, collected 546 400 tonnes of WEEE through its official take-back system while in Australia, just 35 per cent of about 122 000 tonnes of end-of-life televisions were recycled, a significant improvement from 9 per cent in 2008 (Baldé *et al.* 2017). In 2015, China officially collected a total of 71.4 million units of televisions, refrigerators, washing machines, air conditioners, and personal computers (TRWAC), which are regulated by China WEEE, or about 44 per cent of their total generation in mainland China in the same year, whereas the amount and percentage in 2012 were only 0.99 million units and 6.97 per cent, respectively. (Tan *et al.* 2018)

Recycling technologies currently include two processes:

i. pre-processing: to disassemble devices, remove of hazardous components, separate material streams into metal, glass, plastic through dismantling, shredding and mechanical separation; and
ii. end processing: to recover metals, such as copper, gold, silver and palladium, usually using pyro/hydro/bio metallurgical treatment (Tran and Salhofer 2018; Kumar *et al.* 2017).

Developing countries tend to rely on the informal sector. In developing countries, such as China, India, Pakistan, Philippines and Viet Nam, the majority of WEEE is collected by the informal sector. In Viet Nam, for example, WEEE is collected by private collectors and separated into several categories:

i. devices for reuse;
ii. devices for refurbishment; and
iii. devices for recycling.

After collection, WEEE dismantling or refurbishing is carried out; reusable parts are separated for reuse while non-reusable ones are sent to recycling facilities (Thang and Anh 2016). Informal WEEE recycling is widely practised using rudimentary technology in unauthorised workshops or at households in craft villages. In these sites, lead and copper are usually retrieved though open burning or burning in primitive furnaces, while precious metals – gold, platinum, palladium and silver – are recovered from printed circuit boards through acid extraction (Ikhlayel 2018; Vats and Singh 2014). Such informal WEEE recycling is usually carried out in small clusters in or around specific cities such as Delhi and Bangalore in India; previously in Qingyuan village, Taizhou, Longtang Town and Guiyu in China; Dong Mai, Te Lo, Trang Minh Ngu Xa craft villages in Viet Nam and farming villages of Kalasin Province in Thailand (Tran and Salhofer 2018).

More than 95 per cent of WEEE in India is handled by the unorganised informal sector using non-scientific processing techniques (Herat 2018). China, however, has recently formalised WEEE recycling through four national pilot projects and National Voluntary Collective Initiatives, 109 WEEE recycling plants have been established with a total capacity of 161 million TRWAC units. As a result, the amount of TRWAC dismantled and recycled in regulated enterprises reached 79.9 million units in 2017 (Ministry of Ecology and Environment of China, 2018). In the Pacific Island countries, there was no official collection rate of WEEE in 2016 and its management is predominantly informal. Due to geographic characteristics with economic, logistic and land limitations, these countries have significant amounts of WEEE stockpiled waiting for disposal (Baldé *et al.* 2017).

An extended producer responsibility (EPR) mechanism has been adopted in several Asia-Pacific countries but implementation still varies. Globally, the number of countries which have separate regulations/legislation on the management of WEEE has increased in recent years, but they still do not exist in many developing countries (Baldé *et al.* 2017). Extended producer responsibility is a good tool for WEEE management, however, it still faces many constraints in developing countries due to inadequate physical infrastructure, low awareness and ineffective enforcement (Hotta *et al.* 2008). In Asia and the Pacific, Japan and the Republic of Korea have effective functioning EPR schemes for the key waste streams, supported by a solid monitoring and enforcement frameworks. China, India, Indonesia and Viet Nam have started to develop EPR programmes, but these are not yet fully implemented. Malaysia and Thailand are also embarking on the path towards EPR for WEEE, although these initiatives generally rely on the voluntary participation of producers (OECD 2014). In Pacific Island countries, EPR is still not popular and only New Caledonia has implemented a mechanism for WEEE, which is managed by a non-profit environmental organisation (TRECODEC) (Baldé *et al.* 2017).

The emerging problem of PV and battery waste has not yet been adequately recognised in this region. As of 2016, none of the Asia-Pacific countries had specific regulations on the management of PV waste WEEE and it is still considered as general or industrial waste (IRENA and IEA-PVPS 2016). This situation must surely change given the large volumes of such waste expected in the near future.

Implications for industry.

Eco-design and formal recycling facilities in developing countries should be developed. The information and communication technology industry should enhance eco-design, in which toxic materials are replaced with environmentally-friendly ones and products designed in such a way that they are easy to repair and/or recycle. Standards for materials usage should be established for all electrical and electronic products and harmonised across the region. Formalisation of a WEEE treatment system through the construction of modern recycling plants and establishment of collection networks should be implemented in developing countries, which are hotspots of WEEE such as China, India and Viet Nam (Feng *et al.* 2013).

Policy implications.

Illegal importation of waste should be controlled, while WEEE inventory and EPR mechanisms should be promoted. Asian developing countries should take stricter measures to control the illegal importation of waste, including WEEE, and avoid the associated environmental risks. A statistical system for WEEE monitoring/inventories should be established at national levels to effectively support policy and strategy development. Methods for WEEE estimation/inventories, such as the sales obsolescence method, survey scale-up method, hybrid sales obsolescence, trade data method and mass balance method (Kumar *et al*. 2017) should be synthesised and provided with detailed guidance to all stakeholders.

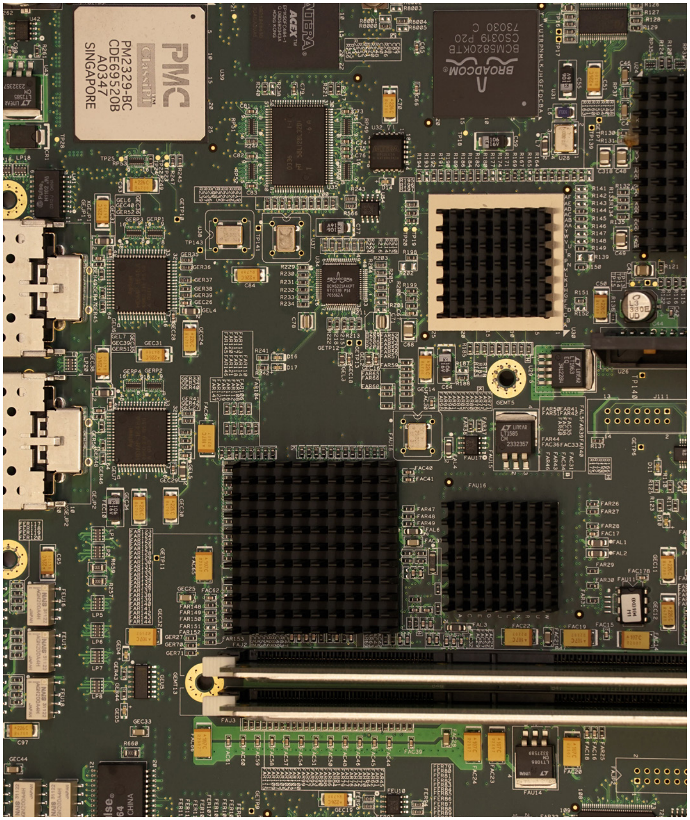
Governments of developing countries in Asia and the Pacific should consider designing, promulgating and implementing legislation on WEEE management. Special attention should be paid to EPR mechanisms with several principles to be taken into consideration:

i. objectives should focus on protecting the environment and human health;
ii. roles and responsibilities of stakeholders, such as consumers, producers/importers, and recycling organisations, should be very clearly defined;
iii. enforcement should be effectively implemented; and
iv. transparency of the system with clear flows of collected fees and charges. (Perry *et al.* 2018)

Additionally, specific regulations on PV waste management should be adopted either under EPR mechanisms or through special policies. Recycling technologies for EV batteries should also be further enhanced.

Heath protection should be provided to workers involved in WEEE treatment. Investigations should be carried out and policy measures developed to ensure health protection for people engaged in WEEE treatment processes, and awareness of WEEE management issues and health impacts raised.

Regional collaboration for better WEEE management should be promoted, with special attention paid to Pacific Island countries. International cooperation is very important in the delivery of state-of-the-art treatment technologies, best management practices and effective policies in developing countries including China, India, and Viet Nam. Regional initiatives, such as the Global Partnership for E-waste Statistics, and other projects on technology transfer should be promoted. Such regional projects/initiatives are significant especially for the Pacific Island countries as they face many constraints in terms of economics, logistics and land use under climate change and sea-level rise projections. Models of mobile plants, portable recycling systems and regional recycling centres should be investigated and developed for these countries.



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CHAPTER 6
Microplastics and Nanomaterials

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KEY QUESTIONS

- Plastics form such an ubiquitous contribution to modern society, why is there emerging concern about plastic pollution and the use of microplastics?
- Many new uses are being posed for nanomaterials, but is there any evidence that they might adversely impact on the environment?
- How are microplastics and nanomaterials entering the environment and why are they not removed in wastewater treatment plants?
- What are the major environmental concerns about microplastics in marine and freshwater environments?
- What controls may be necessary to limit the potential damage caused by microplastics and nanomaterials?

Plastics are valuable and everywhere. Our modern world is experiencing an age of plastics, bringing many benefits to all aspects of society. Unfortunately, the main strength and durability features that make plastic so valuable also make it one of the world's most persistent pollutants, accumulating in landfills, agricultural fields, forests, streams and lakes and the oceans (Barnes *et al.* 2009). Approximately 8.3 billion tonnes of plastic have been produced since the emergence of large-scale production in the early 20th century, more than most other man-made materials (Geyer *et al.* 2017). With a current annual output of 335 million tonnes (Mt) (Plastic Europe 2017), plastics production is expected to double by 2035 and almost quadruple by 2050 (World Economic Forum 2016). About 8 per cent of oil production is used in making plastics, with about one third used for packaging, mostly single-use and easily discarded (Thompson *et al.* 2009). Only 9 per cent of a cumulative total of 6.3 billion tonnes of plastic waste generated from 1950 to 2015 has been recycled, while most has been discarded either in landfill or accumulating in fragile ecosystems such as the world's oceans (Geyer *et al.* 2017). Between 4.8 and 12.7 Mt of plastics flows into the world's oceans from land-based sources each year (Jambeck *et al.* 2015), costing over US$ 13 billion in environmental damage to the marine ecosystem annually (Thevenon *et al.* 2014; UNEP 2014a; 2014b).

Macro-plastics are killing many marine animals. Hundreds of marine species have been found to ingest plastic particles, presumably mistaking them for food. Owing to visual similarities of marine debris to natural prey items, sea turtles have a tendency to eat soft and transparent debris and have been found to ingest plastic bags (Schuyler *et al.* 2014), probably mistaking them for jellyfish (Schuyler *et al.* 2014; Campani *et al.* 2013; Tourinho *et al.* 2010; Mrosovsky *et al.* 2009). These plastic items can then bioaccumulate through predator-prey relationships. For some animals the amount of plastic consumed can even lead to their death through blockages in their stomach or perforation of internal organs (Teuten *et al.* 2009). Other animals become physically entangled in discarded plastic items like fishing nets or the plastic rings from six packs of beer and may die from strangulation, starvation or drowning (Ryan *et al.* 2009).

Microplastics are an emerging concern. While there is justifiable concern about the large plastic items contributing to huge floating garbage patches in the ocean, there is increasing concern about microplastics in marine, freshwater and terrestrial environments (Ng *et al.* 2018; Wang *et al.* 2017; Li *et al.* 2016; Barnes *et al.* 2009). The term microplastic was first coined in 2004 (Thompson *et al.* 2004) and defined by the United States National Oceanic and Atmospheric Administration (NOAA) as a size fraction less than 5 millimetres in diameter, including particles in the nano-size range (Arthur *et al.* 2008), which can be either manufactured micro-sized plastic particles (primary sources), or broken-down fragments of larger plastic items (secondary sources). These microplastics can be deliberately added to products as, for example, scrubbers in cosmetics, abrasive beads for cleaning ships, releases from manufacturing plants, or broken-down pieces of larger weathering plastic items (Teuten *et al.* 2009). They are also released from washing man-made fibres.

Microplastic particles are being found everywhere. Studies in the past few decades have demonstrated that microplastics are found in global habitats stretching from surface and subsurface waters (Cozar *et al.* 2014; Desforges *et al.* 2014), shorelines (Browne *et al.* 2011; Browne *et al.* 2010), beaches (Hidalgo-Ruz *et al.* 2012) and seafloors, to freshwater bodies (Besseling *et al.* 2017; McCormick *et al.* 2016), even pervading remote areas of the polar regions (Waller *et al.* 2017; Bergmann *et al.* 2016; Lusher *et al.* 2015) and the deep-sea (Taylor *et al.* 2016; Van Cauwenberghe *et al.* 2013; Woodall *et al.* 2014), including the Atlantic (Cozar *et al.* 2017; Law *et al.* 2010), the Pacific (Law *et al.* 2014; Eriksen *et al.* 2013; Goldstein *et al.* 2012) and the Arctic (Obbard *et al.* 2014).

The transboundary movements of microplastics are believed to be governed by physical characteristics – density, size, shape and buoyancy – and ocean dynamic conditions – hydrodynamic processes, winds, waves and ocean currents (Zhang 2017; Critchell *et al*. 2016; Vermeiren *et al.* 2016). Once in the oceans, density is a primary variable influencing their environmental fate. Microplastics denser than seawater, including polyvinyl chloride, most probably sink and accumulate in bottom sediments, whereas low-density microplastics, such as polypropylene, tend to float at the sea surface and disperse in the water column (Chubarenko *et al.* 2016). However, additives, weathering, biofouling processes and colonisation of organisms might alter the density of microplastics and contribute to decreasing buoyancy and accelerating the sinking rate (Cole *et al.* 2016; Kowalski *et al.* 2016; Lobelle *et al.* 2011). The presence of low-density microplastics has been documented in subtidal sediments (Claessens *et al.* 2011), benthic sediments in coastal seas and the deep seafloor (Shimanaga *et al.* 2016; Van Cauwenberghe *et al.* 2015; Van Cauwenberghe *et al.* 2013). Even Arctic Sea ice contains up to 238 microplastic particles per cubic metre of water – as much as 2 000 times the concentrations reported in the Great Pacific Garbage Patch (Obbard *et al.* 2014). Concentrations of more than 12 000 particles were found per litre of sea ice in core samples taken from five regions of the Arctic Ocean (Peeken *et al.* 2018). Trillions of tiny plastic particles have been trapped in Arctic ice and they could be released once that ice melts.

Physical effects of ingesting microplastics are uncertain. There appears to be little evidence of direct health effects from ingestion of microplastics, however, as they pass through the various routes in the ocean indicated in Figure 6.1 (Wright *et al.* 2013). Nevertheless, microplastics have been found in a wide range of detritovores and bottom deposit feeders – amphipods, polychaetes, sea cucumbers and crustaceans; planktivores – zooplankton; filter feeders – copepods; suspension feeders – sea urchins, starfish and bivalve molluscs; etc. (Wright *et al.* 2013). Various studies have revealed potentially harmful effects of microplastics such as:

i. inhibition of photosynthesis by absorption on to phytoplankton (Bhattacharya *et al.* 2010);
ii. decreased feeding in zooplankton (Cole *et al.* 2013);
iii. low fecundity in zooplankton (Lee *et al.* 2013);

iv. weight loss of lugworms (Besseling *et al.* 2013);
v. decreased energy reserves in lugworms (Wright *et al.* 2013);
vi. inflammatory immune response in mussels (Von Moos *et al.* 2012);
vii. decreased oocyte number, diameter and sperm velocity and larval yield and development in oysters (Sussarellu *et al.* 2016); and
viii. inhibited hatching, decreased growth rates and responses to olfactory threat cues, and altered feeding preferences and innate behaviour of European perch larvae (Lönnstedt and Eklöv 2016).

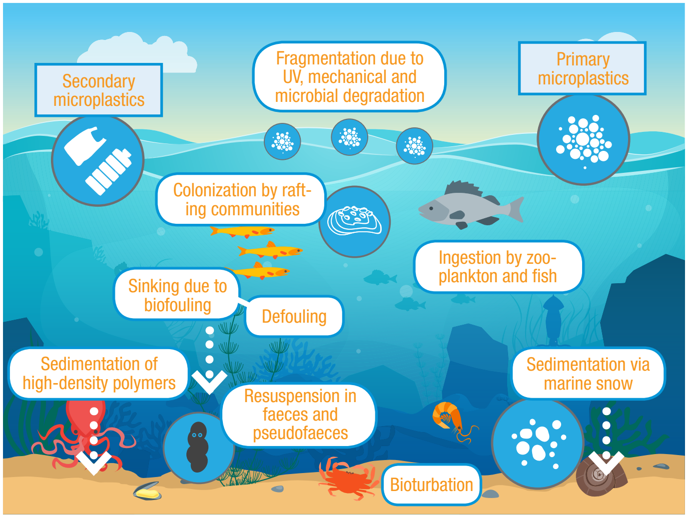

Figure 6.1: Fate of plastics in the ocean
Source: Wright et al. 2013

Microplastics adsorb toxic chemicals. These microscopic particles may, however, contain low concentrations of organic contaminants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides, polybrominated diphenylesters, alkylphenols and bisphenol A (BPA)) either added during manufacture to soften the plastic or as a flame retardant or adsorbed from seawater (Teuten *et al.* 2009). Some of these chemicals can penetrate cells and may be endocrine disruptors, whereas the larger microplastic particles are excluded. Adsorption of chemicals on to microplastics may also retard their biodegradation. Multiple persistent organic pollutants (POPs), PCBs, PAHs and dioxins have been found in plastic pellets on beaches (Avio *et al.* 2015). Sediment ingesting organisms have been found to have elevated levels of these contaminants transferred by microplastics, but possibly no higher than from only ingesting similarly contaminated sediment (Teuten *et al.* 2009). Laboratory exposures show that reproduction of marine organisms is affected by phthalates, which are added to plastics as softeners, and BPA, with molluscs and amphibians sensitive to very low concentrations (Thompson *et al.* 2009).

Microplastics may transfer toxic chemicals to marine organisms. The extent to which such toxic chemicals are transferred to marine organisms varies widely (Browne *et al.* 2013). One experiment exposing different levels of pyrene, a common PAH, to polyethylene and polystyrene pellets ingested by filter feeding mussels found that, after seven days exposure, there was increased pyrene in the mussels' gills and digestive glands compared to the concentrations on the pellets and up to 13 times as high as in control specimens (Avio *et al.* 2015). Additional research is necessary, however, in the natural environment, especially on bioaccumulation and long-term exposure effects (Thompson *et al.* 2009).

Microplastics also affect freshwater ecosystems. Until recently less studied than marine ecosystems, microplastics have also been widely detected in freshwater environments. Most of the impact phenomena are the same as for the marine environment, but freshwater ecosystems are closer to the direct source, for example, from laundry and cosmetics), if not the breakdown products found in the marine environment (Eerkes-Medrano *et al.* 2015). Investigation found that 83 per cent of 159 tap water samples from more than a dozen nations on five continents, including Ecuador, Indonesia, Uganda and the United States, were contaminated with microfibres, indicating that microplastics have penetrated tap water around world (Tyree and Morrison 2017; Wang *et al.* 2017) found a negative correlation between distance from urban areas and microplastic concentrations in Chinese lakes, suggesting a clear anthropogenic origin. Freshwater species known to ingest microplastics include invertebrates, fish and possibly birds. It should also be noted that marine microplastics are mostly sourced from freshwater river discharges, although discharge of litter, nets, etc. at sea are also involved.

Wastewater treatment systems do not capture all microplastics. The identified pathways of microplastics released into the ocean include stormwater outflows, sewage effluents, riverine inputs, fishing, aquaculture gear, accidental spillage from ships as well as atmospheric outfalls (Dris *et al.* 2016). Wastewater treatment plants are one of the major pathways for microplastics in the aquatic environment, but the release ratio depends on the design and efficiency of the wastewater treatment facility as well as regional differences. There is limited research on effectiveness of treatment plants in capturing microplastics prior to their entering the aquatic environment. Studies in European and Russian plants found that the percentage of microplastics captured in sewage sludge varies from 24 per cent to 100 per cent (Echelpoel 2014; HELCOM 2014; Magnusson and Noren 2014; Leslie *et al.* 2012), depending on the type and shapes of microplastics, treatment technologies and identification methods. A membrane bioreactor increased the capture of smaller particles by 90 per cent compared to plants that did not have the technology (Magnusson and Wahlberg 2014). In addition, density is an important property affecting microplastics behaviour/movement in water (Besseling *et al.* 2017; Law *et al.* 2010). Buoyant particles are more likely to escape both skimming and settling processes (Carr *et al.* 2016; Echepoel 2014). The captured microplastics in wastewater treatment plants are suspended in sewage sludge, then often applied to agricultural land as a source of fertiliser and subsequently leached into rivers (Ng *et al.* 2018). Small, less visible microplastics, such as microbeads from personal care and cosmetic products and fibres from textiles, can pass through preliminary sewage treatment screens – typically coarse ones of > 6 millimetres and finer ones of 1.5–6 millimetres (Vesilind 2003) – and end up in aquatic environments. For example, between 8.2 and 93 billion microplastic and synthetic fibres are discharged annually from wastewater treatment plants in Germany (Mintenig *et al.* 2014) and a plant in the United Kingdom could release up to 65 million microplastic beads, fibres, etc. into receiving water every day (Murphy *et al.* 2016).

Microplastics may transfer toxic chemicals to humans through marine or freshwater organisms. The extent of toxic chemicals passing from microplastics to marine or freshwater organisms and on to humans, and the health impacts that might result, is less clear (Eerkes-Medrano *et al.* 2015). Using animal models and bio-monitored body burdens, the chemicals used in the manufacture of plastics have been shown to have potential health effects, including reproductive abnormalities (Thompson *et al.* 2009). Their concentrations, however, are more likely to have come from direct environmental sources such as exposure to house dust rather than from eating contaminated fish. Ingestion, inhalation and skin contact are all important routes for humans. Safe exposure levels, however, may not have taken adequate account of interactions between multiple contaminants or especially vulnerable children or pregnant women (Thompson *et al.* 2009). Microplastics may accumulate in the gastrointestinal tract and have been found in human faeces. Up to nine different plastic types were identified, which can ultimately transmit toxic chemicals and pathogens into the body. The smallest microplastic particles are capable of entering the blood stream, lymphatic system and may even reach the liver (MacMillan 2018).

Nanomaterials are also raising concern but even less is known about their impact on the environment. In 2003, Colvin stated "*currently, nanomaterial exposures and health effects are unlikely to pose any substantial risk to public health*" although noting that, as use increases, unintended environmental consequences will also increase (Colvin 2003). By 2008, manufacture of nanomaterials had increased exponentially and could be classified as carbonaceous nanomaterials; metal oxides; semiconductor materials, including quantum dots; zero-valent metals such as iron, silver and gold; and nano-polymers (Klaine *et al.* 2008). These were being manufactured into nanofibers, nanowires and nanosheets, but manufacturing and release to the environment was proceeding faster than measurement or assessments of their impact on the environment. In the most recent review, greater caution is called for "*due to the uncertainties and irregularities in shape, size, and chemical compositions, the presence of certain nanomaterials may exert adverse impacts on the environment as well as human health*" (Kabir *et al.* 2018). The conclusion of this latest review, however, suggests that greater application of the precautionary principle may be necessary as "*it is very difficult to reach any conclusion about the ecological effects and environmental stability of nanomaterials*" (Kabir *et al.* 2018).

Implications for industry.

Part of the response to marine plastic litter has been to propose the production of biodegradable plastics (UNEP 2015). While various products have been released that claim to be biodegradable, they may only be biodegradable under certain industrial conditions, may release other additives, could make recycling more difficult, and may encourage people to litter more frequently. In addition, there is limited information on the microplastics that could form as these plastics degrade in the natural environment. As microplastics in cosmetics can be replaced with more natural products including cellulose, crushed walnut shells, coffee grounds, apricot kernels and beeswax (Bhattacharya 2016), there is ample scope for industry to find replacements or face eventual bans on the use of micro-beads – in 2016, 55 cosmetic companies in the Republic of Korea announced that they were discontinuing the use of microbeads. For nanomaterials, while the benefits are acknowledged, greater attention needs to be paid to the environmental fate of these materials and their potential environmental and health impacts.

Policy implications:

While there are some efforts underway to address marine plastics in Asia-Pacific countries such as Japan, India, Indonesia, Philippines and Thailand as well as the United States and Europe, for example, the European Commission Marine Strategy Framework Directive's Technical Subgroup on Marine Litter, there is less attention being paid to microplastics in freshwater rivers as a pathway to the marine environment, and/or their potential impacts in lake ecosystems. As indicated by Eerkes-Medrano *et al.* (2015) "*concerted efforts on all fronts, including survey(s), monitoring, research and policy, will be required to better understand any emergent threats posed by microplastics in freshwater systems and to develop appropriate, informed strategies for managing them*". Some organisations, such as the United States National Institute for Occupational Safety and Health, have proposed occupational exposure limits to nanomaterials and it has been suggested that manufacturers should be obligated to provide detailed information to the relevant environment agencies (Kabir *et al.* 2018). In September 2016, the Ministry of Food and Drug Safety of the Republic of Korea revised its Regulation on Safety Standards for Cosmetics and banned the importation and production of cosmetics containing microbeads from July 2017 and the sale of cosmetics containing microbeads from July 2018. In January 2017, the Ministry issued a further notice on the revision of regulations on non-medicinal products which banned the importation and production of toothpaste and tooth whiteners containing microbeads from July 2017 and their sale from July 2018.

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CHAPTER 7
Pharmaceuticals and Personal Care Products

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KEY QUESTIONS

- Pharmaceuticals and personal care products make our lives healthier and contribute to individual and societal well-being, so why should we be concerned about their impact on the environment?
- Is there any evidence that these products and their break-down components are causing environmental concerns?
- How are these materials entering the environment, directly or indirectly?
- Why are these chemical compounds not being removed in traditional wastewater treatment facilities?
- What further research is needed to underpin additional policies, regulations or controls on these products?

Chemical products are proliferating. As the world modernises and the human population grows, around 500 000 chemical products, including 4 000 pharmaceuticals, are used to make lives more fulfilling, easier and healthier. Generally, the manufacture of these products has been increasingly controlled since the 1970s, but releases of chemicals and their metabolites (break-down products) after use and their pathways through the environment, into water, soil, and biota, and back to human consumption are not only less controlled, but also not well understood (Figure 7.1).

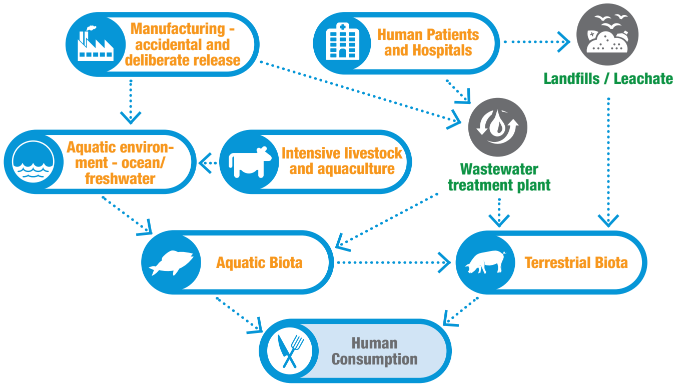

Figure 7.1: Chemical paths to the environment and back to humans

Source: Arnold et al. 2014

Are we witnessing another *Silent Spring*? Just as the modern era of environmental protection can partly be traced back to Rachel Carson's *Silent Spring* (1962), which alerted the world to the impact of the indiscriminate use of pesticides and particularly dichlorodiphenyltrichloroethane (DDT), there is emerging concern about the potential impacts of pharmaceuticals, both for humans and livestock, and personal care products (Arnold *et al.* 2014). This issue first came to public attention in the 1990s with some evidence that oestrogen discharge to the aquatic environment was causing feminisation of fish (Larson 2014). Additionally, the rapid decline of 99 per cent of vultures in South Asia was traced to the use of a veterinary anti-inflammatory drug in cattle, diclofenac, which persisted in the dead animals on which the vultures feed (Cuthbert *et al.* 2014). The veterinary use of diclofenac was banned in 2006 and it was replaced by meloxicam as a vulture-safe alternative.

Manufacturing remains a source of pollution. Of course, pollution from manufacturing industries has not been eliminated completely, especially in developing countries. Pharmaceutical concentrations from a wastewater treatment plant in India receiving wastewater from a concentration of 90 pharmaceutical manufacturing plants, for example, were found to be greater than in humans taking the medicines (Larson 2014). One broad spectrum antibiotic, ciprofloxacin, was in concentrations high enough to treat 44 000 patients and potentially toxic to exposed organisms. Similarly, in China high levels of oxytetracycline, a degradation product of penicillin, and ethinyloestradiol have been observed in treated effluent and receiving waters (Larson 2014). Unfortunately, municipal wastewater treatment plants are not required to specifically control such chemicals in the effluent stream.

Contaminants of emerging concern. The United States Environment Protection Authority (USEPA) refers to pharmaceuticals, personal care products, hormones, pathogens and others as contaminants of emerging concern (CECs), as it is the concern which is emerging, not the contamination, which started many years ago. Increasingly sophisticated analytical methods have allowed the tracing of these CECs from wastewater treatment plants, septic tank systems, landfill, and intensive agricultural production systems to surface and groundwater, sediments, soil and biota.

Consumers are often not aware of the toxic nature of cosmetic products. Despite warnings from the United States Food and Drug Administration to limit the amount in cosmetics, many skin whitening products contain above 1 000 parts per million (ppm) of mercury to increase the whitening effect. Lead acetate, a suspected neurotoxin, is found in hair dyes while formaldehyde, a known carcinogen, is found in nearly 20 per cent of cosmetic products. Other chemicals of concern include phthalates, parabens and triclosan, which are linked to cancer, reproduction problems and brain development in children (Scientific American 2017). These chemicals find their way into the wastewater treatment system and then, receiving waters.

Contaminants are not removed in water treatment systems. In a major national study, the United States Environmental Protection Agency (USEPA) and the United States Geological Survey (USGS) addressed the concern that these CECs may also be contaminating drinking water, with potential human health exposures, as they may pass through water treatment systems without being fully removed. The study traced 247 CECs in water sources and in 25 water treatment plants across 24 states (Kolpin *et al.* 2017). Of the 247 CECs, 148 were detected in the water source and 121 in the treated drinking water. Pharmaceuticals and anthropogenic waste indicators were infrequently detected, but perfluoroalkyl and polyfluoroalkyl substances, used in consumer products such as carpets, clothes, upholstery, food wrapping paper, fire-fighting foam and metal plating, and inorganic material were more resistant to treatment (Glassmeyer *et al.* 2017; Furlong *et al.* 2017).

Pharmaceuticals and illicit drugs in drinking water. In a similar study in Lisbon, Portugal, 31 pharmaceuticals were monitored in the drinking water supply system, with only 16 detected in concentrations of 0.005–46 nanograms per litre (ng/L) in raw water and 0.09-46 ng/L in drinking water. The health risk from exposure to these trace levels of pharmaceuticals was regarded as extremely unlikely (de Jesus Gaffney *et al.* 2017). Treatment processes appear to be successful in reducing potential pharmaceutical contamination of drinking water (Furlong *et al.* 2017). A study of a wastewater treatment plant in South Africa, however, found evidence of eight illicit drugs in wastewater along with 40 emerging contaminants, upstream and downstream of the wastewater treatment plant (Archer *et al.* 2017). As this wastewater treatment plant's effluent feeds into a dam that supplies 6 per cent of municipal drinking water, the health implications of these findings were of concern. Although most of the CECs were reduced in the effluent, some remained, even at higher concentrations after treatment (Archer *et al.* 2017).

Antibiotics are increasingly used in agriculture. As the human population increases, incomes rise and a preference for meat consumption increases, there is increasing pressure to increase livestock production. Intensive animal rearing, however, also increases the possibility of disease wiping out a farmer's whole herd or flock of animals. As a result, there is an understandable willingness to treat animals with the same antibiotics that have been so successful in minimising human disease, as well as trying to promote growth through their use. As evidenced in the overuse of antibiotics for humans, there is a plausible link between antibiotic resistance in animals spilling over into the human population, as shown in Figure 7.2 (Chang *et al.* 2015).

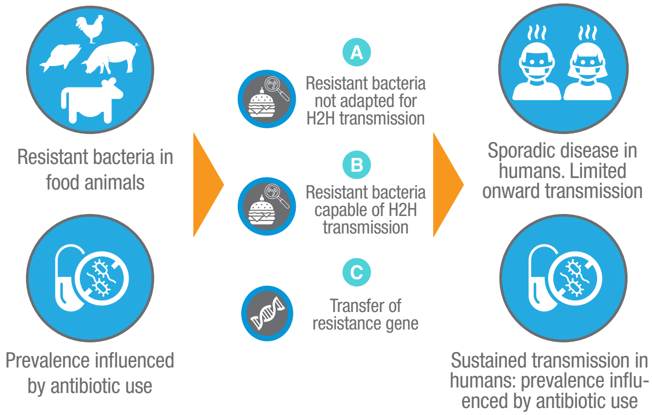

Figure 7.2: Possible links between antibiotic use in agriculture and human disease

Source: Chang et al. 2015

Finding the right balance is paramount. There is abundant concern about the rise in antibiotic resistance and the emergence of super bugs in the medical profession (Levy and Marshall 2004), so the possibility that animal rearing practices are making this situation worse is attracting considerable research attention. There are three main ways that antibiotic resistant bacteria could transfer from animals to humans:

i. direct infection;
ii. species barrier breaches; or
iii. transfer of resistance genes (Chang *et al.* 2015).

A fourth, although unproven pathway is through insects, such as mosquitoes, flies or cockroaches, in environments where humans and animals are living in close proximity, as experienced in much of rural Asia (Ghosh 2014). Finding the right balance between increased food security and losing the last barrier against fighting disease requires considerable precaution, carefully crafted policies and regulations, and increased research attention.

Persistent contaminants in soil, water, and sediment. Pharmaceuticals persistent in the environment, including synthetic hormones, anti-inflammatory drugs and anti-depressants, have been detected in soil, surface and groundwater, marine ecosystems and sediment, and are regarded as pseudo-persistent (Arnold *et al.* 2014). For example, the antidepressant, Prozac, (active ingredient fluoxetine) is barely degraded in wastewater treatment plants, sewage or soil over many months. This same chemical has a bioconcentration factor of more than 1 000 in freshwater mussels, which are consumed by other animals in the food chain. In Australia, antidepressants were estimated to be consumed by the iconic native platypus in concentrations equivalent to half the average human daily dose through consuming contaminated invertebrates in urban streams, with unknown consequences for aquatic biota (Richmond *et al.* 2018).

Endocrine disruption in marine ecosystems. In addition to human health concerns, CECs at low concentrations have been found to affect reproductive and thyroid endocrine system pathways of fish and other species, impacting fecundity and spawning, and ultimately fish populations. Pharmaceutical uptake can be through the gills or skin or through the food chain (Arnold *et al.* 2014). Combinations of CECs and bioaccumulation in the aquatic environment may have a greater impact than laboratory testing of individual CECs, suggesting the need for more eco-toxicological studies in polluted waters (Archer *et al.* 2017; Brodin *et al.* 2014). Fish species may also experience behavioural changes in response to bio-accumulation of pharmaceuticals, but not all species will react the same way (Brodin *et al.* 2014).

Behavioural changes caused by medications. The CECs may indirectly affect wildlife populations through changes in behaviour that reduce their fitness to survive in the wild (Brodin *et al.* 2014). Carbamazepine, used to treat epilepsy and bipolar disorder, is commonly found in sewage-contaminated locations and could modify the behaviour of predators and prey exposed to it. Furthermore, the recent decline in bird populations across Europe could potentially be related to foraging on fields irrigated with treated effluent or sewage sludge (Arnold *et al.* 2014).

A sleeping giant issue in Asia? In general, these topics have not been well studied in Asia and Africa, although these may be the regions with the least effective controls over sources, use, and discharge of CECs (Kookana *et al.* 2014). In developing countries, leakage from septic systems or from open defecation may be more important routes for CECs into the environment than from wastewater treatment systems. Certainly, increased field research is needed, along with raised awareness among Asian drinking water companies and consumers.

Implications for industry.

The most obvious thing for industry to do in relation to this problem is to prevent any accidental or deliberate discharges from manufacturing facilities. The second implication is to design products for the environment as well as for profit, which may require additional regulatory controls over manufacturing if this is not done on a voluntary basis. Consumers also need to be made more aware of issues related to the disposal of these products, as leachate from landfills may be a significant source of aquatic contamination. For pharmaceuticals, pharmacies may need to offer take-back facilities for products that have expired or are no longer needed. The agricultural sector may need additional controls if antibiotics are being used illegally and alternatives need to be used, where available. Where livestock live close to human populations, increased attention should be paid to cleanliness and insect control.

Policy implications.

As for the case of the vulture decline in South Asia, there may be equally important eco-toxicological impacts that are passing unnoticed in developing countries, suggesting the need for vastly increased research attention to this emerging issue. Such research is needed to underpin potential policy responses and increased attention to environmental compliance and enforcement. Additional policies and regulations may be needed to control antibiotic use in the livestock industry, along with improved compliance and enforcement. Consumers need to be provided with accurate information on the potential implications of the indiscriminate disposal of medicines as well as the potentially toxic concentrations in products like whitening creams.

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CHAPTER 8
Conclusions

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Industrialisation is a dual edged sword. Industrialisation is proceeding rapidly in Asia and the Pacific and has been instrumental in lifting millions of people out of poverty. The downside of that industrialisation has been air, water and land pollution, depletion of natural resources and its contribution to climate change. As industrial production systems transition in advanced countries from the archaic steam engines and belt-and-pulley systems to robots, artificial intelligence and blockchain technologies, there are multiple opportunities to minimise the impact of industry on the environment.

Modernisation of industry in the Asia-Pacific region is proceeding slowly and not all countries and citizens are benefiting it. This uneven development has detrimental impacts on quality-of-life issues, promotes informal settlements and encourages illegal migration. The vast disparity between rich and poor in many of the region's developing countries creates barriers to development and potential for conflict.

Some modernisation is easily available to large enterprises but not to small- and medium- sized enterprises. One low hanging fruit that offers cost savings as well as environmental benefits in all countries is energy efficiency. This opportunity has not always been adopted for a range of reasons and barriers to implementation, but can be scaled up from pilot demonstrations, especially in small- and medium-sized enterprises where they are often located in clusters. Mandatory energy audits may be one avenue to rapid capitalisation on the opportunities provided by energy efficiency.

Most of the region's industry for future urban and peri-urban expansion is yet to be built. Accordingly demand for cement and steel will continue to grow and massive increases in production and consumption of construction materials are required for road and rail infrastructure, buildings, utilities etc. Industrial waste management needs will also increase and industrial capacity to handle waste needs to expand significantly. Municipal solid waste needs to be treated as an industrial resource and converted into useful products. Unfortunately, rural- to-urban migration is often to peri-urban areas with unplanned development and under-serviced areas, which has serious implications for the environmental and human health.

The speed and magnitude of industrialisation in Asia is much greater than occurred historically in the West over a much longer period. Accordingly, government regulations and controls are struggling to keep up with this rapid development. Multi-benefit, multi-governance packaging is needed to achieve an optimal mix of finance and governance. Governance innovation can support the packaging of policies – low cost environmental sensors, citizen science and e-governance.

Air pollution has re-emerged as a significant health risk in Asia and the Pacific. Air pollution episodes are becoming more frequent and widespread. Air pollution was more visible in the past but while less visible, it is more measurable today. There is a better understanding of multiple pollutants, their sources and the potential co-benefits of addressing air pollution at source. For many countries, the political stakes are higher due to increasing public concern and modern communications.

Designing environmentally beneficial industrial processes avoid future problems. End-of-pipe and wastewater treatment plants are still needed but are not the long-term solution. New industries and retrofitting existing industries need to focus on designing industrial processes to minimise water use and pollution. For some emerging issues, like anti-microbial resistance, and nanomaterials and microplastics pollution, additional regulation is required as standard wastewater treatment systems are not effective. Additionally, industrialised agriculture is often not treated in the same way as other industries yet may be more difficult to manage than industrial point sources.

Nature and industry are mutually connected. Many environmental solutions may come from a better understanding of how nature works. Biomimicry, bioprospecting and artificial photosynthesis are examples of how we can learn from nature and innovate industrial solutions. There is a danger, however, in assuming that industry can find solutions that will replace natural systems and their contribution to people, without creating new environmental concerns. Maintaining biodiversity, if for no other reason, is a fail-safe insurance scheme for future human needs.

Whole systems need to be analysed to avoid merely shifting problems. The issue of recycling used solar panels and other WEEE is a good example of how one solution often leads to new environmental problems, highlighting the need for designing for the environment from the outset. Factories need to be designed to be zero-waste, or to use the waste output from other factories. Water-supply systems need to be designed by taking the entire water cycle, from upstream watershed management to recycling wastewater within factories, offices and households, into account.

Other emerging issues also need attention. This short report has not been able to cover all emerging concerns. Industry, for example, needs to consider industrial accidents, and how disasters can impact industrial sites which then, in turn, ecosystems in a cascade. A recent example was the earthquake that led to a tsunami that impacted nuclear power plants in Japan in 2011. Such cascading can occur when any disaster strikes but rapidly industrialising middle-income countries may face the highest risks. Another emerging issue of concern associated with industry is soil contamination, from atmospheric fallout and direct application of industrial waste and sewage sludge on land.

Advances in monitoring capacity offers new solutions to tracking pharmaceuticals, personal-care products, nanomaterials, microplastics, etc. before they become problematic in freshwater and marine environments. The precautionary principle suggests, however, that there is a need to be very careful in allowing new materials that have never existed in nature to be released to the environment without careful research into the possible environmental impacts.

The lack of research into these emerging issues in the Asia-Pacific region is a major concern. There could be several environmental issues, similar to those documented above, are not recognised in developing countries of the Asia-Pacific region. Most of the relevant research has been conducted in developed countries, where the sources, disposal and fate of contaminants of emerging concern may be quite different from those in developing countries.

ACKNOWLEDGEMENTS

UN Environment would like to acknowledge the contribution of the Institute for Global Environmental Strategies, especially the editors Tetsuo Kuyama and Peter King, authors and other contributors who have reviewed the draft document and suggested additional material, and staff at the UN Environment Regional Office for Asia-Pacific, who have edited and finalised the document before posting it online.

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