Economic benefits of action and costs of inaction

Foundational paper for GCO-II

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This document is a third draft of the "foundational paper" for the GCO II. It takes into account feedback received during the GCO II conference and the authors' meeting between 18 and 21st June 2018 as well as subsequent written comments provided in November 2018 and January 2019.

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1 Introduction

Large numbers of chemical substances are manufactured, distributed and incorporated into mixtures, articles and products globally. They generate substantial economic and social benefits. These benefits arise at the point of sale (global revenues were €3.3 trillion in 2016[1] [2]) and along various supply chains. These arise from various essential functionalities that chemicals impart in products, efficiencies they support in manufacturing processes and the innovations they enable.

At the same time, substantial economic costs are associated with exposure to harmful chemicals. These include the direct costs of health care treatment, costs arising from time off work, impaired capability and lost productivity. Costs are borne by business in occupational healthcare and from accidents, litigation and reputational damage. Costs also arise from impaired functioning of ecosystem services, biodiversity and terrestrial and aquatic wildlife. These costs manifest near and far, in the short, medium and long term and arise throughout the lifecycle of products. These economic *costs* reflect what we *value;* our health and that of our families, our leisure and recreation as well as the health of the environment. These costs also reflect differences between private benefits (or costs) and social costs (or benefits). Economists refer to these as externalities (Box 1), which are distributed within and between countries across the globe.

Box 1: Externalities – differences between private costs (benefits) and social costs (benefits)

Consumption, production and investment decisions often affect people not directly involved, I.e. they are external to a specific transaction. These can be positive or negative. So called technical externalities - where external effects impact the consumption and production opportunities of others, but the market price of the product in question doesn't reflect these external costs – are the most common.

Environmental pollution, be it from harmful chemicals or any other source, is a classic example of a negative externality. Here, polluting organisations make decisions based on the marginal costs incurred by them and their marginal benefits. Additional social costs borne by the society due to their production externalities are seldom considered. These costs are not borne by the polluter, not passed on to the consumer so do not feature in market prices or in economic transactions. The social costs of production are therefore greater than the private costs.

These negative externalities may be accompanied by positive externalities. This may include Research and Development (R&D) investment, perhaps by the same polluter, which results in functional benefits facilitated by chemical use in new products. These new products may support weight savings and longer product lifetimes which, for example, may result in wider social benefits beyond the private cost.

The main problem with externalities is that market outcomes may not be efficient, leading to overproduction of goods with negative externalities and under production of those with positive. Externalities pose significant policy problems when individuals, households and companies do not internalise the indirect costs (or benefits) from their economic transactions (Helbling 2017).

The second session of the UN Environmental Assembly (UNEA2) Resolution on chemicals and waste requested the Executive Director to address, in preparing the Global Chemicals Outlook II (GCO-II), inter alia the work carried out in relation to lacking or inadequate data to assess progress towards sustainable

[1] Source Cefic (2017) Facts and Figures 2017. World chemical sales: geographic breakdown http://www.cefic.org/Facts-and-Figures/

[2] Euro to Dollar exchange rate conversion based on a 2016 annual average taken from the IRS Yearly Average Exchange Rates for Converting Foreign Currencies into U.S. Dollars, where $1 equates to €0.940. Source: https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates

development goals[3]. This builds on the findings of the "Costs of Inaction" report, published by UNEP in 2013[4].

Since this 2013 study new analysis has emerged on the economic externalities associated with harmful chemicals. This has raised awareness about chemical pollution and sparked debate on the underlying science as well as elements of the economic analysis. There have been some significant methodological steps forward in the assessment of the costs associated with chemical use, but these are not without criticism. Whilst significant methodological challenges, data gaps and uncertainties remain, a growing body of analysis indicates that the ongoing economic costs from exposure to harmful chemicals are globally significant and currently underestimated. Much economic analysis focusses on Europe and the United States and is still limited to a comparatively small number of substance-effect pairings. Disproportionate burdens may be falling on low and middle-income countries from ongoing chemical exposure. Globally, known risks are evolving and new ones emerging.

There is a need for new research on the economic costs of chemicals exposure, requiring a wider body of biomarker and biomonitoring data. This need is more acute in low and middle-income countries. The global scale and complexity of chemical pollution should be given greater prominence by the public and policy makers. A study akin to the Stern review of the economics of climate change should be considered to aid greater awareness and facilitate new avenues of research.

2 Questions to be addressed

This review paper assesses the current state of knowledge of the economic benefits of action (BoA) as well as the costs of inaction (CoI) to ensure the sound management of chemicals. It features the results of recent studies as well as a discussion on the evolution of relevant methodologies. It draws on published or peer-reviewed literature only. Whilst the focus is on publications since UNEP's 2013 report, earlier references are used where the evolution of methodologies are discussed.

This paper relies on secondary literature only and no new primary economic estimates have been derived for the current paper. It does not claim to cover the entire literature but has been selective in its coverage. Whilst any economic assessment should consider the overall net effect of policy action, neither the wider economic effects related to innovation, nor the costs of regulatory implementation and compliance are considered in detail in this paper. In addition, economic assessment is ongoing in public agencies in various jurisdictions across the world, as well as in academia. For the former, it is not possible to cover the large technical literature in this paper – but specific examples are noted. For the latter, much of the published work focus on a relatively small number of substance effect parings and are largely confined to studies in Europe and North America.

Any assessment of the economic costs attributed to chemicals builds on a series of underlying analyses. The extent of this is limited by the scientific data, particularly epidemiological and biomonitoring data. The strength or otherwise of evidence on causality between individual substances and human health (and environmental) effects is an ongoing debate that continues to evolve as new associations are discovered (see for example Harremoes *et al*. 2002). This is a complex subject involving much debate. The focus of this chapter is on the economic methods and results obtained in trying to chart complex relationships

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[3] http://web.unep.org/about/cpr/documents/resolutions-and-documents-second-session-un-environment-assembly

[4] UNEP (2013). Costs of inaction on the sound management of chemicals Nairobi, Kenya.

between chemicals and exposure, rather than review the underlying epidemiological evidence. This review explores the current state of knowledge along two dimensions:

- **Economic benefits of action (BoA):** Benefits of action is reduced or avoided damage to human health and/or the environment from reduced/avoided exposure to dangerous chemicals. This may include the estimated benefits arising from the number of lives saved, or cancers avoided, for example. This is typically estimated ex-post, using information on effects from regulatory and voluntary action already taken (i.e. it "looks back") but seeks to guide, refine and improve future action. This analysis is examined first. These "economic" benefits include both market and non-market effects, discussed below. Such estimates are methodologically complicated and the results uncertain, often reported within wide ranges.

- **Economic costs of inaction (CoI):** The Organisation for Economic Co-operation and Development (OECD 2008) defines inaction as no new policies beyond those which currently exist. So this analysis relates to damage to human health and/or the environment that is estimated to be occurring at present - or that can be reasonably expected to occur in the future - under the current policy framework. This points to the need for new or amended action, be that regulatory, voluntary or a combination of the two.

Based on this the following questions are explored:

- What are the **key findings from recent studies** on the benefits of action and the costs of inaction on the sound management of chemicals?
  - What data exist on **regional disparities**, estimates of the **evolution of costs** and **emerging evidence of risk**?
  - Which **new data and insights** have become available since UNEP's 2013 Costs of Inaction report? What data is still missing?

- Which **approaches and methodologies** are being used (or are under consideration/development) by different stakeholders (e.g. public agencies, businesses, NGOs)?
  - How are these evolving?
  - What is known about their effectiveness and which gaps remain in calculating the costs of inaction/benefits of action?
  - Which methodological challenges and significant knowledge and data gaps exist and what are the most promising developments for addressing these?

- How far are the costs of inaction on the sound management of chemicals **already addressed in national policies and decision-making processes**?

- To what extent can or does the **private sector** identify and internalise their costs? Which gaps remain?

- In light of the analysis and insights gained, what are the **lessons-learned** relevant for global consideration and policymaking, including from a Low and middle-income country (LMIC) perspective?

2.1 Economic cost and benefit assessments rely on both market-based and non market-based approaches

Monetary valuation is an important aspect of this paper and in policy analysis more generally. This section briefly explores what components are typically assessed in BoA and CoI studies and considers how the results should be interpreted.

2.1.1 Market-based valuation approaches

Where economic estimates of cost and benefit are derived in the context of environmental concerns, these involve the attribution of monetary value to a range of different things.

Most current analysis relates to the economic costs of chemical exposure on human health. This encompasses the cost of healthcare provision as well as the economic effects of poor health, including mortality. The cost of diagnosis by healthcare professionals, the cost of treatment as well as economic effects from the loss of working days are taken into account. Longer term productivity losses across populations are also incorporated. Several recent studies have placed monetary values on effects of chemical exposure, pre and post birth, and subsequent cognitive ability measured in IQ. This has then been linked to productivity and lifetime earnings and hence to an economic value attributed to exposure.

More limited quantitative/monetary information currently exists on the direct economic effects of chemical exposure on the environment (i.e. functioning of ecosystems, natural capital and biodiversity and species health).

2.1.2 Non-market-based valuation approaches

Individuals reveal their preference for good health or quality of life through payments that avoid adverse health conditions. However, the psychological costs of suffering due to mortality and morbidity cannot be easily captured. These values are not reflected in the formal accounting measures like Gross Domestic Product (GDP). However, various revealed preference or stated preference methods are developed to estimate the value of suffering associated with mortality and morbidity. These include identifying average “willingness to pay (WTP)” either for good health (one’s own or others’), to avoid a health condition, avoided damage to the environment, to environmental amenities and the associated loss of function/quality of life. Monetary estimates use a wide range of available unit values based on these WTP data, which includes the values of statistical life (VOSL) as well as the Disability Adjusted Life Year (DALY) and the Quality Adjusted Life Year (QALY). Assessments using these metrics seek to reflect the societal aggregate of personal valuations.

While a comparison of the aggregate values identified with gross domestic product (GDP) is useful when dealing with market-based approaches, the same comparison may be insufficient and potentially misleading when economic analysis uses non-market-based approaches. **Error! Reference source not found.**. (Box 2).

Box 2: Value, utility and "economic" cost

Utility is a measure of satisfaction/dissatisfaction that individuals get by consuming a certain good or service. For example, each individual draws satisfaction from enjoying good health, leisure or another consumption good. Conversely dissatisfaction arises from poor heath, excessive work or exposure to pollution. The additional satisfaction/dissatisfaction that one gets by consuming additional units of each good is the deemed marginal utility or marginal disutility.

Economic value is the amount of money each individual spends or is willing to spend to obtain the utility from a certain good. Again, if the good results in disutility, she may pay to avoid that good or accept some compensation to continue suffering from this disutility. This economic value is a measure of the maximum amount of money that the individual is willing to pay/able to pay to derive utility from the good.

Economic value and market price, however, need not be the same. The value of the good is the opportunity cost of getting that good, i.e. the amount one gives up to satisfy one's utility. The value of leisure for example, is the potential wage income sacrificed to obtain it. Economic value can be proxied with market price where markets are competitive, and markets exist for the good.

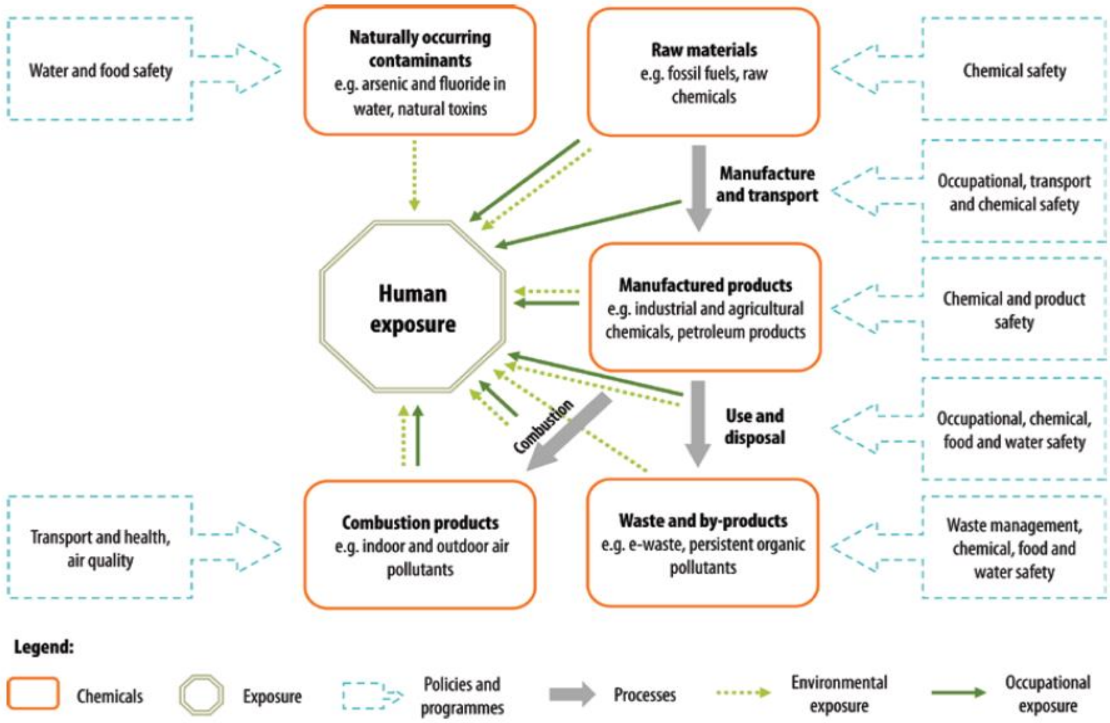
Certain goods may not only have use values but non-use, existence or intrinsic values. In such cases the value and price cannot be the same. Human life for example, has intrinsic value – beyond any market price or effect; the lives of the older people and others not in the labour market are clearly not less valuable. In these cases, economists rely on various non-market valuation techniques to estimate the value of life. So costs refer to the economic costs or the opportunity costs of consuming a good (or bad). The cost of pollution is the opportunity cost of healthy life or what the individual sacrifices to pay for his or her ill health.

3 How have economists identified the benefits of action and costs of inaction? A review of methods.

3.1 Economic assessment seeks to reflect complex relationships

Precise determinations of the burden from chemical exposure is challenging and requires various analytical stages. There are multiple pathways of exposure to chemicals as well as multiple causal factors of the adverse effects. These are individual and institutional and reflect genetic predisposition, one's access to health care, the precautionary measures taken as well as the external policy environment. Clearly these differ significantly across the globe. The time period covered in analysis, the latency of diseases and level and duration of exposure as well as the toxicity of the chemicals all impact the final outcome. Figure 1 presents these pathways of potential exposure, impact policy and programme areas.

Figure 1. Human exposure to chemicals throughout their lifecycle and selected programmes relevant to their prevention



Source: Press Ustun et al. (2011)

3.2 Output indicators – *VOLY, DALY and YOLL*

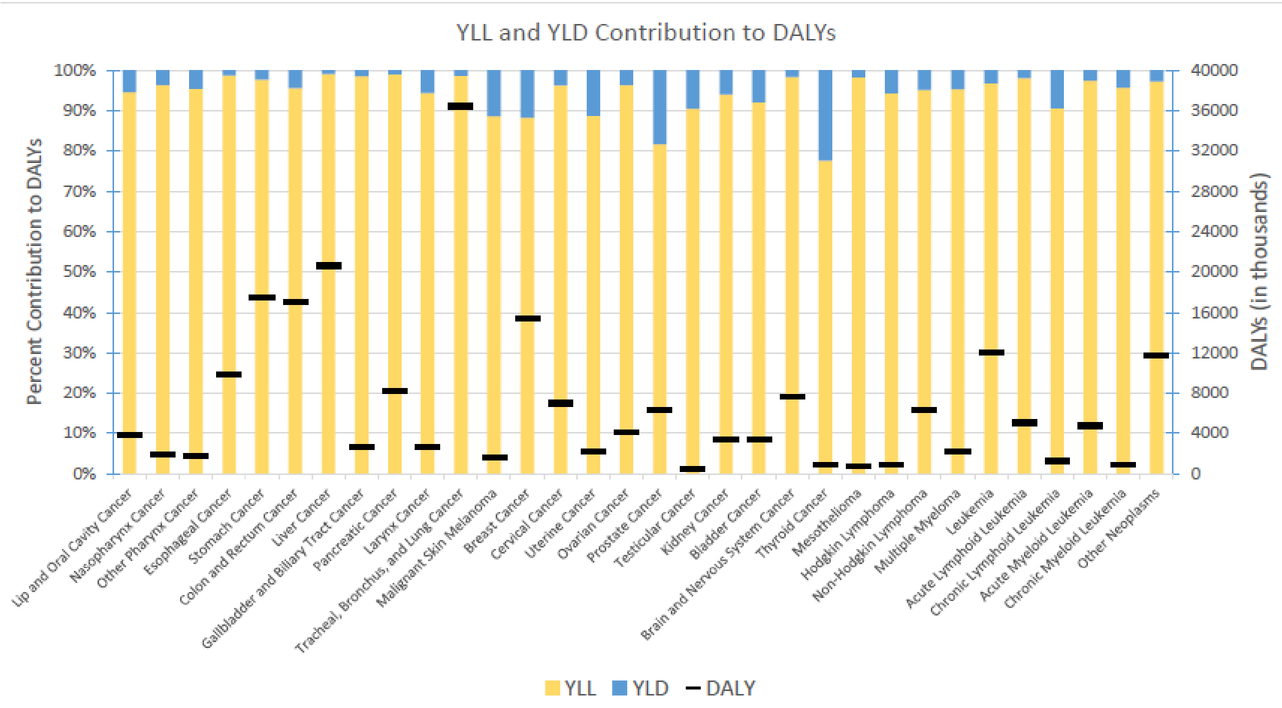
Commonly used output indicators of health are mortality (premature death), morbidity and life years. Arriving at these requires establishing the epidemiological relationship between chemical exposure and specific health outcomes (exposure response/dose-response function). Such dose response functions establish the relation between exposure to chemicals and the probability of developing a disease along with the probability of mortality or morbidity. The relationship has often been expressed in terms of the value of life years (VOLY) or the years of life lost equivalent (YOLL).

The global burden of disease (GBD) published by the World Development Report (1993, 2013) computes a Disability adjusted life year (DALY) metric that takes into account both the duration and quality of life. DALY is a useful metric that quantifies the relationship between exposure and proven outcome using expert inputs (Delphi technique), giving the relative importance of major diseases and their risk factors. There has been an increased understanding of different risk factors attributable to different diseases over recent years. The original GBD study was later updated by the WHO with methodological improvements and added detail in 2004[5]. A new GBD study was published by the Institute for Health Metrics and Evaluation (IHME[6]) in 2010. This also provided regional estimates of deaths and DALYs for the years 1990, 2005 and 2010 (with some methodological changes) from the WHO calculations. The latest available WHO and IHME data relate to 2016 (key data from both are summarized later in this paper).

[5] http://www.who.int/healthinfo/global_burden_disease/about/en/
[6] http://www.healthdata.org/gbd

Another approach to understand the risk of morbidity from chemical impact is to convert this into years of life lost equivalent (YOLL). This measures premature - preventable - mortality. The indicator is standardized and measured as years lost per 100,000 inhabitants by summing up death occurring at each age (up to 70 years old) and multiplying this with the number of years of standard life expectancy (based on public health statistics). Figure 2, for instance indicates the relation between DALYs, YLL and YLD (years of healthy life lost due to disability) in the case of cancer.

Figure 2. Relation between DALY, YLL and YLD in the case of cancer



Source: Global burden of disease Cancer collaboration (2016).

The epidemiologic data (as presented by the GBD, YOLL etc.) usefully indicates the extent of the health problem, but cannot indicate the resources lost due to fatal and non-fatal losses (for example time, human capital, and well-being). Public health interventions by governments (such as REACH, the Minamata convention on mercury, various acts banning the use of lead in petrol etc.) result in marginal improvements in health of individuals and ecosystems. To understand how the benefits of action compare to the costs (including the costs of inaction), economic values are placed on these marginal benefits. As noted in section 2.1, by assigning monetary value to the benefits, the intention is not to "value life" but to value incremental changes in health status or in health risks (Krupnick, 2007).

Individuals reveal how much they value these small changes in health or risk through their behavior. Individuals make choices in their decisions every day in the way they eat, work, activities they perform, choice of lifestyle etc. Through this their values for health and life are "revealed". These often involve market choices and trade-offs between risk reductions and incremental costs. Such trade-offs form a basis for estimating the value of statistical life (VSL). The VSL is a measure of collective willingness to pay (WTP) for a small reduction in the annual mortality/risk of death (Viscusi 1993, Alberini et al. 2004). As such the valuation of statistical life is not a universal constant rather it reflects trade-offs made in certain situations between different alternative ways of reducing risk. (Dockins et al. 2004). The economic value of benefits of health improvements can then be understood in terms of the willingness-to-pay by an individual or society for reducing the risk of suffering and death (see Mishan 1971).

Statistical value of life estimates provide useful reference values for benefit cost analyses as well as to capture the reduction in risk of fatal disease like cancer. A meta-analysis of VSL studies by the OECD (2011) recommends for the EU-27 a VSL of $3.6 million (2005 prices), with an indicative range of 1.8 to 5.4 million dollars. Another study by ECHA (2016a), recommends a VSL of €3.5 million (2012 prices) for the EU28. Some values of statistical value of life used by US Regulatory agencies based on Viscusi and Aldy (2003) related to several regulations related directly or indirectly to chemicals is given in Table 1. These have relied on cost-based approaches and on revealed and stated willingness to pay (for avoiding the risk/suffering).

Table 1: Benefits of different interventions (in million USD) estimated in terms of value of statistical life

1985	Environmental Protection Agency	Regulation of fuels and fuel additives, gasoline lead content (50 FR 9400)	$1.7
1988	Environmental Protection Agency	Protection of Stratospheric Ozone (53FR 30566)	$4.8
1996	Food Safety and Inspection Service	Pathogen Reduction, Hazard Analysis and Critical Control Point Systems (61 FR 38806)	$1.9
1996	Food and Drug Administration	Regulations restricting the sale and distribution of cigarettes and smokeless tobacco to protect children and adolescents (61 FR 44396)	$2.7
1996	Environmental Protection Agency	Requirements for lead based paint activities in target housing and child occupied facilities (61 FR 52602)	$6.3
1999	Environmental Protection Agency	Control of Air Pollution from New Motor Vehicles. Tier 2 motor vehicle emission standards and gasoline sulphur control requirements (65 FR	$3.9 - $6.3
1999	Environmental Protection Agency	Radon in drinking water – health risk reduction and cost analysis (64 FR 9560)	$6.3

Source: Adapted from Viscusi and Aldi (2003)

3.3 Valuation methodologies

Using metrics such as DALYs and YOLL calculations, several methods have been developed and used. These are summarised below (see also figure 3) and discussed in more detail in the sections that follow.

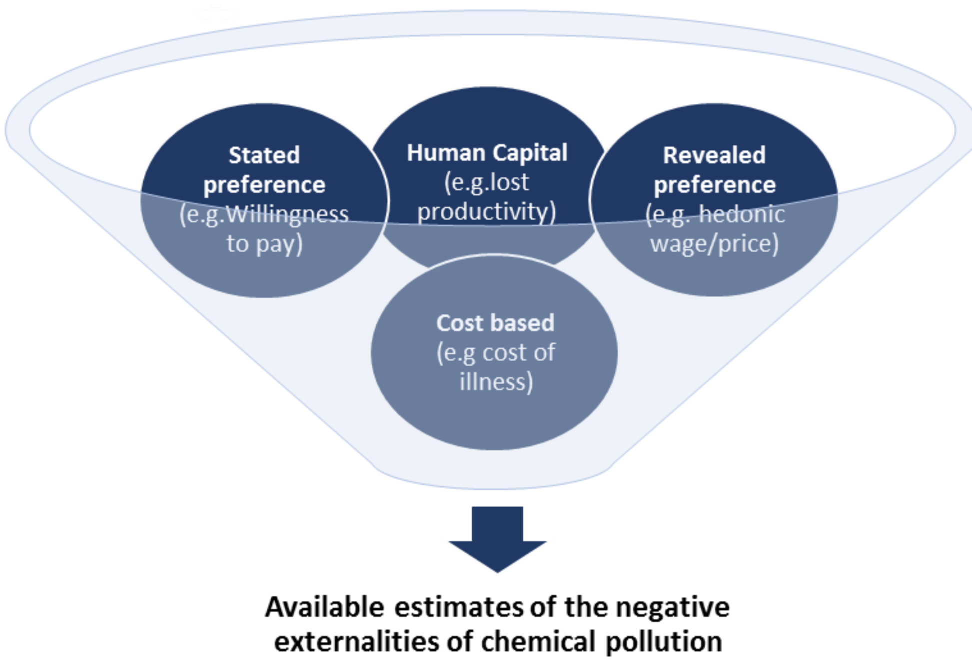
- The simplest approach to understand the benefits of a health intervention is through estimating avoided costs (costs that can be avoided due to reduced suffering). This involves directly observing the health costs, estimating the value of lost earnings due to disease and of lost economic productivity due to suffering etc. This is referred to as the ***cost of illness*** approach (or the avoided cost approach).

- Another involves estimating the value of lost earnings from reduced/lost economic productivity due to disease, suffering or impaired capability. This is referred to as the ***human capital*** approach. This relates to labour and wages but involves complex assumptions about labour market participation, future earnings and discount rates.

- A third approach is to use directly or indirectly available market information that ***reveals individual preferences***. For example, observing the wage differentials between risky and non-risky jobs. Sometimes the individuals incur voluntary expenditures (avertive expenditures) to reduce the risk of death or suffering (safety equipment, seat belts etc.). By collecting the data on such expenditure directly or indirectly, it is possible to discern the willingness-to-pay for improvements in risk or health status.

- The ***stated preference** technique* relies on asking people questions through surveys to elicit their willingness-to-pay for certain interventions that would improve their health (the stated preference method). Examples of this include the contingent valuation method (which involves asking questions on their willingness to pay) conjoint analysis (eliciting preference from particular combinations of attributes and alternatives). Both these techniques, if properly applied, produce valid results (Krupnick, 1987) but with some limitations.

Figure 3: Identifying economic costs of inaction and benefits of action



3.3.1.1 *The cost of illness approach*

This approach involves evaluating in economic terms the burden of the disease through the direct and indirect expenditures incurred in treating fatal and non-fatal cases (Hodgson and Meiners 1982). Here the average number of days of medical care are multiplied with the direct health care costs (expenditures for medications, doctor visits, hospitalization etc.), the direct non-health care costs (travelling, waiting costs etc.) and the indirect costs (human capital costs due to adverse health outcomes, loss in productivity etc.). Overall this provides an estimate of the cost burden of the illness per reported medical case (see Table 2 for different types of costs).

However, the indirect costs incurred in terms of reduction in quality of life, pain and suffering etc. cannot be easily quantified and thus are usually not included due to lack of data. The productivity loss due to mortality and morbidity requires different estimation techniques (like the human capital approach, see below). A key limitation of the cost of illness approach is the difficulty in obtaining data on accurate medical costs for mortality and morbidity. There is a likelihood that the medical costs are often over estimated and obtaining accurate cost data is difficult as the costs depend on the length of the suffering, absence from work or work day loss and hospital admission days. The cost estimates are extremely sensitive to the technology used in treatment, its efficiency and efficacy. This can vary substantially within and between countries, systems of medicine, the nature of treatment, cluster of symptoms as well as by age, gender and individual constitution/genetic factors.

The second major drawback of the cost of illness approach is in estimating the value of lost productivity. Average wages are used but the approach severely underestimates the value of lost productivity of children, students and the old who are not in the labour force as well as lost productivity of the household due to the illness of a family member. The approach also disregards the impact on physical and human capital accumulation (Rice 2000: WHO 2009). The advantage of the approach is that it is easy to observe health expenditures, and this decreases the disposable income of households.

Table 2. Examples of costs associated with different health outcomes

Direct health care costs		Direct non-health care costs	Indirect costs
- Institutional inpatient care Hospitalization specialized unit (ICU, CCU) Nursing home Terminal care or Hospice - Institutional outpatient service Clinic and ER - Home health care - Physician services General practitioner (GPs) Specialists - Ancillary services Nurses (RNs, Nursing Aid) Nutritionists Physical therapist Ambulance - Overhead allocated to technology Fixed costs of utilities Space and storage Support services Capital costs (depreciation) Construction of facilities Relocation expenses Device or equipment cost - Variable costs of utilities - Medications (prescription and non-prescription) Drug costs Training in new procedures Dispensing and administration Monitoring	- Devices and applications - Drugs, supplies, devices provided by household - Diagnostic test Imaging Laboratory testing - Treatment services Surgery Consumable supplies, personnel time, equipment Treatment of complications Blood products Oxygen Radiation therapy Special diets - Prevention services Screening space Vaccination, prophylaxis Disease prevention in contacts of known cases - Rehabilitation - Training and education Health education Self-care training for patients Life-support skills for general population	- Social services Counseling Retraining - Program evaluation Monitoring impact of program or technology Data analysis - Repair of property destruction - Legal costs - Transportation costs - Time (searching, traveling, waiting etc.) - Childcare or Housekeeping	- Productivity losses Morbidity Mortality Impairment Jon absenteeism - Foregone leisure time - Time spent by family & visitors attending patient

Source: Jo (2014). "Cost-of-Illness Studies: Concepts, Scopes, and Methods." *Clinical and Molecular Hepatology* 20.4 (2014): 327–337. *PMC*. Web. 4 June 2018.

3.3.2 Human capital approach

The most common approach to estimating the indirect costs of fatal and non-fatal illness is the human capital approach. Human beings are capital assets as they use their education, embodied knowledge, skills and experience as factors of production. Exposure to harmful chemicals leads to premature mortality and morbidity, thereby impacting productivity. The approach quantifies the net present value of lost future earnings (a proxy for productivity loss) because of episodes of illness. In computing the net present value of earnings lost, both the direct and indirect output related losses are considered. The method is used not only to estimate the loss/gain in individual productivity due to ill health/good health but also the loss/gain in a nation's productivity due to presence/absence of various health interventions.

For example, Bradley et al. (2008), used a human capital approach to estimate the productivity loss due to Cancer in the United States. The study projected the productivity loss from cancer to be approximately $147.6 billion for 2020. If imputed earnings lost due to caregiving and household activity are included, the productivity losses increased to $308 billion in 2020. Similarly, a 1% annual reduction in lung, colorectal, breast, leukemia, pancreatic, and brain cancer mortality increased productivity by $814 million per year.

More recently the World Bank (2018) estimated the monetary losses of human capital in 172 countries from fatal health conductions caused by exposure to air pollution. The study estimated that globally, the annual income losses from premature mortality caused by air pollution exposure totaled nearly US$179 billion in 2015, an increase of about US$47 billion (or 36 percent in real terms) since 1995. The study found a reduction in human capital due to reduction in labour force participation induced by air pollution (See Table 3). Several studies noted in the following sections of this paper have used the human capital approach, specifically in the context of chemical exposure.

The main drawback of this method is that the future earnings do not accurately represent future production. It also assumes that the workers are irreplaceable. The popularity of this method stems from the fact that it is possible to highlight the economic losses suffered by an earning individual. But it does not highlight the suffering of those who are not in the labour force (e.g. the retired or children yet to enter).

Table 3: Labour income losses from Air Pollution,1995-2015 billion US$

Region	1995	2000	2005	2010	2015
East Asia and Pacific	29.9	35.3	40.3	47.9	62.0
Europe and Central Asia	31.0	26.2	26.7	25.4	26.3
Latin America and the Caribbean	15.0	12.4	10.1	9.1	9.2
Middle East and North Africa	4.6	4.5	4.4	5.3	6.5
North America	15.9	17.8	20.8	19.0	20.7
South Asia	19.6	21.1	21.1	25.3	32.7
Sub-Saharan Africa	15.4	15.4	15.8	18.2	21.3
Total	131.4	132.6	139	150.2	178.7

Source: World Bank (2018).

3.3.3 Revealed Preference Approaches

3.3.3.1 *Hedonic wage/hedonic price*

Wage differentials exist between risky and non-risky professions. People who accept risky jobs need a wage premium compared to those in less risky professions. Depending on aversion towards risk, workers make trade-offs between wages and benefits. Similarly, housing markets often reflect environmental preferences in prices (proximity to a lake or park for example). This is the basis of the hedonic theory which was first used by Rosen (1974). Wage-risk or price-risk relationships can be estimated by regressing the job attributes (or structural attributes), fatal and non-fatal risk perception (threat perception), individuals specific attributes including the human capital attributes (e.g. in case of hedonic wages the education, skills etc.) and other labour market conditions. The equilibrium represents the wage-risk trade-offs for marginal changes in risk and the implicit price indicates the marginal willingness to accept risk or the marginal willingness to pay to avoid it. See Viscusi and Aldy (2003) for a meta-analysis of studies that estimated the hedonic wage/hedonic price with respect to the environment.

3.3.3.2 *Avertive or Defensive expenditures*

Individuals incur expenses to decrease the chance of being exposed to “bads” that impact ill-health. Individual’s health is dependent on several factors including income, education, lifestyle, genetic make-up including how much she spends to protect herself from ill-health. Avertive expenditures are very similar to the health production function developed by Grossman (1972). For example, farmers spraying pesticides or workers using paints use masks, gloves etc. to protect themselves from the ill effects. Through avertive expenditures, people reveal their willingness to pay to reduce risk. If the expenditures are incurred after the negative health outcome occurs, they are referred to as mitigating expenditures.

The main limitation of this approach is that avertive expenditures do not indicate the extent of the problem but allow specific data on how individuals perceive risk, which also reflect factors not necessarily related to the environment.

3.3.4 Stated Preference Approach

Stated Preference techniques elicit people’s responses under different well-specified hypothetical scenarios to understand their willingness to pay/accept as compensation to reduce/avoid the risk. This is often the only technique available for non-use values. By stating their willingness to pay, consumers express their value on what they would pay if harmful chemicals are eliminated or regulated in the system.

Several studies have used the stated preference method to estimate the values of reducing mortality and morbidity. Most of the studies have used either contingent valuation or conjoint choice experiments. The approach has been used to estimate the health benefits of air pollution reduction, noise pollution and water pollution reduction, acid rain, greenhouse gas mitigation, NO_x reduction, ozone, sulphate, air pollution regulation, particulate matter etc. Several studies combine the scenarios in WTP with Cost of illness questions (Chestnut et al. 2012). Lindhjem et al. (2011) carried out a meta-analysis of Value of statistical life (VSL) using stated preference studies, which ask people their WTP to reduce the risk of dying prematurely from environment, transport and health related risk. The VSL estimates varied significantly depending on the sector causing the mortality risk, the stated preference technique, the payment vehicle, age, the latency of the risk, individual health status, magnitude of risk change as well as socio-economic factors.

However, methodological developments in this field are far from static (Box 3).

Box 3: Current methodological developments - SACAME

A project coordinated by the OECD and funded by the European Commission, called the Socio-economic Analysis of Chemicals by Allowing a better quantification and monetisation of Morbidity and Environmental impacts (SACAME), was established in 2017. It aims to support improved socio-economic analysis from better quantification and monetisation of effects from chemical substances. Longer term the projects objective is to develop harmonised OECD methodologies for estimating the economic costs and benefits of managing chemicals, supporting the implementation of the Strategic Approach to International Chemicals Management (SAICM).

To date several project papers have been published as part of the project between late 2017 and early 2018 evaluating available economic analysis in the context of the regulation of several different chemicals / chemicals groups. These papers draw conclusion on the validity of the available data, its usefulness as well as requirements for new primary research in more than is possible to cover here, but

several of the underlying sources are reviewed in this paper. Papers on Phthalates (Holland 2018), formaldehyde (Hunt and Dale, 2018a); and the solvent methyl-2-pyrrolidone (NMP) (Hunt and Dale, 2018b) have been made available recently, amongst others.

Further papers in the series explore thematic methodological issues, including the challenges using benefit transfer methods (Navrud, 2017) approaches for assessment of PFOA (and Persistent Bioaccumulative and Toxic (PBT) substances more generally, Gabbert, 2018)) and how chemical risk assessments can better support economic analysis in decision making (Chiu, 2017).

Several specific technical conclusions are drawn in the papers. Amongst these:

- **Several studies note variation in existing valuation studies including differences in unit values.**
- **Sparse economic analysis was noted even on comparatively well studied and regulated chemicals such as formaldehyde.**
- **Extensive data gaps are noted and the particular need for new primary evidence in Asia and on Persistent bioaccumulative and toxic (PBT) substances was noted.**
- **Further study is required on the effects of substances individually and collectively to help better target control strategies.**
- **It was noted analyses require multidisciplinary expertise in epidemiology, (eco) toxicology as well as economics and statistics.**

4 Analysis of Status and Key Issues

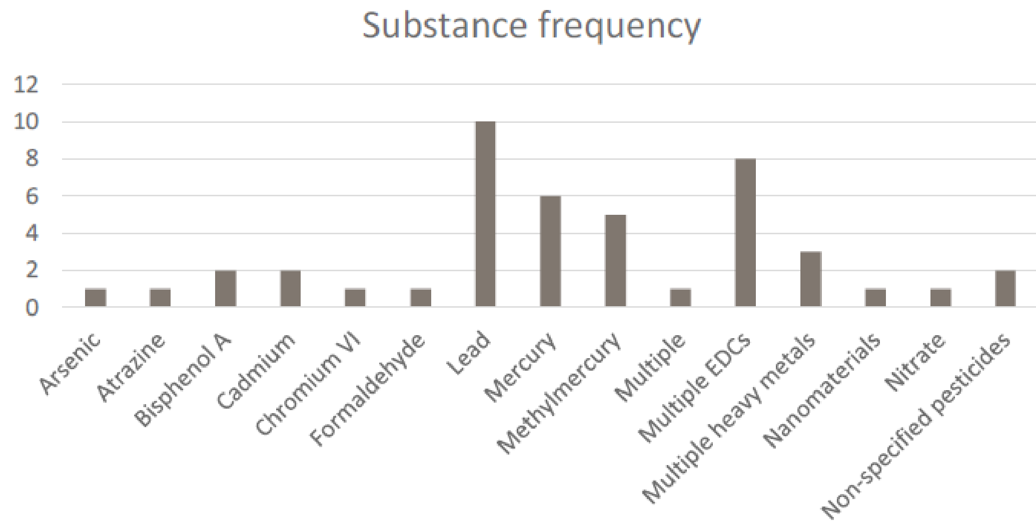
4.1 Overview

This section evaluates key findings from recent studies on the economic benefits of action and cost of inaction. As far as data are available this is disaggregated by world region as well as by the different health and environmental endpoints. First, we provide an overview of some of the chemicals or groups of chemicals that have been studied.

4.1.1 Chemicals evaluated in economic assessment

The assessment of health impacts caused by chemical exposure and quantification of associated costs/benefits at national or global level requires good understanding of exposure-dependent outcomes and distributions of exposures for chemical substances across a population, over time. Dose-response relationships from epidemiological observations, ideally based on robust biomonitoring data, before and after the intervention which can then be used to attribute disease burdens and quantified impacts (Trasande et al. 2015). The use of these functions varies depending on the available evidence. Most economic assessments have focused on a relatively small number of pollution-disease pairings, for which a stronger causal relationship is suggested and where better data exist. Figure 4, taken from a review of relevant literature indicates that heavy metals (lead or mercury), followed by the endocrine disrupting chemicals and pesticides are the most prominent. But overall the coverage of chemical substance is limited, the number of studies uneven and the geographical scope of research confined to only some parts of the globe.

Figure 4. Frequency of substances covered in monetary valuation literature



Source: Sørensen et al. (2016)

- Lead is one of the most widely studied environmental pollutants, but the range of health effects that exposure to lead can cause at low concentrations is only now being fully appreciated (Amec Foster Wheeler, 2017a). In adults, chronic exposure to lead is a risk factor for hypertension, renal failure, cardiovascular disease, and stroke. Neurodevelopmental toxicity (pre- and post-birth) an important consequence of lead toxicity in children (Attina and Trasande, 2013). Various economic impacts have been analysed associated with neurodevelopment. These relate to loss of productivity e.g. cognitive impairment, lowered IQ, and increased risk of attention deficit or hyperactivity. A key economic benefit identified and attributed to reduced lead exposure is increased lifetime economic productivity and earnings, measured through avoided IQ point losses. Nedellec and Rabl (2016) derived a valuation of €17,100 per IQ point lost, based on the marginal effect on productivity and hence lifetime earnings, but other similar monetary relationships have been identified.

- The critical effect of methylmercury (MeHg) exposure is developmental brain toxicity so prenatal exposures are of particular concern (Bellanger et al. 2015). As above, the major component of the social costs incurred by an IQ reduction is loss of productivity and thus a lower earning potential. Dose-response data is relatively well established[7].

- Endocrine disrupting chemicals (EDCs) mimic, block, or alter the actions of normal hormones such as estrogen, testosterone, growth hormone, insulin, and thyroid hormone. A series of studies (Trasande et al. 2015) investigated a list of substances based on a 2012 UNEP/WHO review of possible EDCs and selected disorders and diseases where then authors judged strong epidemiological and toxicological evidence for causation was available. The fraction of disease

[7] Spadaro and Rabl (2008) derived a value of 0.036 IQ point losses due to daily (yearly) intake of MeHg. Bellanger et al. (2013) derived a linear dose-response function with a slope of 0.465 IQ point reduction per 1 µg/g increase in the maternal hair-Hg concentration during pregnancy. Trasande et al. (2016) used linear dose-response relationships from an integrative analysis by Axelrad et al. (2007), who identified a 0.18 IQ point decrement per ppm increase in hair mercury to estimate the corresponding increases in intellectual disability and lost Disability-Adjusted Life Years (DALY).

attributable to EDC exposure was estimated, as were exposure-response relationships; several from the results of a single epidemiology study. These studies focus on specific substances: organochlorine pesticides (e.g. DDE); organophosphate pesticides; bisphenol A, phthalates (e.g. butylbenzyl phthalates; di-2-ethylhexylphthalate) associating these with a range of health effects (the results are discussed later in the paper).

The list of diseases attributed to pollution is judged likely to continue to grow as the environmental distributions and health effects of newer chemical pollutants are better defined and new exposure–disease associations are discovered. The health effects of pollution that are currently recognised and quantified could be the "tip of a much larger iceberg" (see Box 4).

4.2 Air pollution and chemical pollution – where to draw the line?

Many chemicals can cause effects via the atmosphere. Pollutants particularly relevant to this exposure route include particulate matter (e.g., organic and elemental carbon [EC], metals and polycyclic aromatic hydrocarbons [PAHs]), but also carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2)[8]. Only some of these are typically considered in the context of "chemicals" they are more typically grouped under the broader term of air quality / air pollution. This reflects a range of scientific and institutional factors (see Box 3). This paper focusses on chemical effects only, but there is much overlap in the analyses. As such the nature of the effect and the causes of it – whether from specific chemicals or from a range of exposure routes - are highlighted wherever possible.

Box 4: Differences in definition and gaps in understanding – fragmentation of policy response?

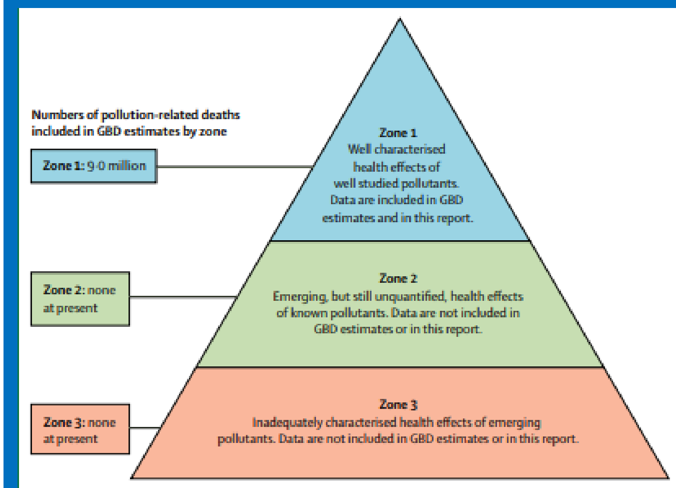
Analyses often define the effects/costs attributed to "chemical exposure" using different definitions. Some define it narrowly, related to the effects of specific substances (or groups of substances) often used in specific applications. Much evidence on the benefits of action, for example, focus on effects of the incremental reduction of lead in petrol, or of occupational carcinogens. Some of this information excludes the assessment of effects from combustion by-products, such as SO_2 and NO_X and VOCs. This in turn may reflect regulatory approaches which some judge may - unintentionally - separate addressing risks from "chemicals" from risk posed by "air pollution/industrial emissions", "water" and "waste" policy or climate change, all of which act on similar end-points.

The Lancet Commission, for example, has taken this wider view defining pollution as "unwanted, often dangerous material that is introduced into to the Earth's environment as a result of human activity that threatens human health and that harms ecosystems". The Lancet assessment draws out effects and their costs from indoor and outdoor air pollution, from water pollution and from soil, heavy metal and chemicals pollution as well as occupational pollutants. Here chemical exposure plays a role – alongside other factors - in all these aspects of pollution, but it is far from the only cause.

The Commission attributes this "fragmentation of agendas" as one of the factors that has led to the neglect of pollution. They note that "In many countries, responsibility for pollution-related disease falls between ministries for health and ministries for the environment and too often belong to neither. Air, water, soil and chemicals pollution are each regulated by different agencies and studied by different research groups. The consequence is that the full scale of pollution and its contribution to the global burden of disease are often are not recognised."

[8] The cardiovascular and respiratory health effects of air pollution have been well documented. There is also evidence for the economic impact that air pollution can have on neurodevelopment (e.g. IQ, executive functions, memory, visual motor abilities (Suades-González et al. 2015)).

It goes on to argue that this is compounded by very real gaps in knowledge on the full effects of all chemical exposures. Reflecting this the Commission developed the concept of the "pollutome" dividing this into three zones. Zone three contains new and emerging pollutants where effects on human health are not yet fully quantified, but widely used [9] (Landrigan et al., 2017).



5 The economic benefits of action – what has been achieved?

This section looks back. It presents key conclusions from recent studies on the costs that have been avoided or reduced from action taken to date.

5.1 Benefits of action – global environmental treaties

5.1.1 Global treaties have "locked in" substantial benefits expected to accrue over the next century.

5.1.1.1 The Ozone Layer

The principal global agreement on depletion of the ozone layer is the UN's Montreal Protocol, adopted by all countries globally[10]. This entered into force in 1989, with several later amendments. As the loss of stratospheric ozone is avoided and the ozone layer recovers, several studies have sought to quantify this treaty's long-term effects. Much of the literature relates to analysis covering the United States, where the cumulative benefits of avoided cancers and cataracts have been estimated at up to US$ 4 trillion (1990-2065) (Table 4).

[9] For example, in the case of neurodevelopment, studies by Grandjean and Landrigan (2006, 2014) identify 12 chemicals known to be toxic to neurodevelopment. However, there are ~200 substances known to be neurotoxic in humans, within the ~1,000 chemicals known to be neurotoxic in animals, and >80,000 other chemicals that have not been adequately tested for neurodevelopmental toxicity. A similar observation has been made for chemicals causing reproductive health effects (Amec Foster Wheeler 2017a). Recent work investigating the impact of EDCs covers <5% of EDCs and a small subset of health effects (Trasande et al., 2015).

[10] See: http://www.undp.org/content/undp/en/home/sustainable-development/environment-and-natural-capital/montreal-protocol.html

In Europe a recent study estimated the cumulative benefits expected to accrue in the EU between 1990 and 2100 at some €7 trillion in total (c. €300 billion per year) from avoided cases of and deaths from skin cancer as well as cataracts. Other non-health related benefits included agricultural and fishing yield increases and energy efficiency improvements arising from Chlorofluorocarbon (CFC) substitution. The longer-term benefits of this international action will accrue as we increasingly avoid the loss of stratospheric ozone and as the ozone layer recovers. The difference between the United States and European studies reflect comparative population sizes (Amec Foster Wheeler 2017a - analysis was based on US EPA 1997 and US EPA 2015). It is noted that there is substantial variability in the results in these studies. This possibly reflects the increased uncertainty on exposure the further one goes forward in time.

Table 4 Estimated benefits of the Montreal protocol and subsequent amendments

Year	Health impacts	Other impacts	Monetary valuations
Slaper et al. (1996), USA, NW Europe	Excess skin cancer cases in 2100 in USA = 1.5 million and in NW Europe (Benelux, Germany, UK, Denmark) = 550,000.	Not assessed	Not assessed
Velders et al. (2001, drawing on ARC, 1997), global 1987-2060	335,000 reduced cancer fatalities, 20 million avoided non-fatal skin cancers, 129 million avoided cataract cases.	Fisheries, agriculture, materials	€1.8 trillion health benefits, €400 billion non-health (1997 prices)
USEPA (1999, Section G), for USA 1990 to 2065.	6.3 million reduced cancer fatalities, 299 million avoided non-fatal skin cancers, 27.5 million avoided cataract cases.	Avoided 7.5% reduction in crop harvests, further impacts on fishing and polymeric materials	$4.2 trillion health benefits, $92.5 billion benefits from avoiding other impacts (2% discount rate, 1990$)
USEPA (2010), USA for cohort with birth years 1985-2100, 1997 Montreal Amendment vs. original Montreal Protocol	22 million fewer cases of cataract.	Not assessed	Not assessed
Van Dijk et al. (2013), global	2 million reduced cancer cases per year in 2030 (14% reduction in incidence) but benefits increase substantially after 2030.	Not assessed	Not assessed
USEPA (2015), USA for cohort with birth years 1890-2100, 2007 Montreal adjustment vs. no control	1.5 to 1.9 million cancer deaths avoided, 283 – 338 million cancer cases avoided, 46 – 51 million cataracts avoided.	Not assessed	Not assessed

Source, Amec Foster Wheeler 2017 a), pages 306-307.

5.1.1.2 *Persistent Organic Pollutants (POPs) and Mercury*

The UN's Stockholm Convention on Persistent Organic Pollutants (POPs) is a global treaty on chemicals which persist in the environment, become widely distributed and accumulate in animal tissue.[11] There is limited data on the economic benefits of action, however a US study evaluated the costs associated with low birth weight babies attributed to perfluorooctanoic acid (PFOA) in US mothers. The associated costs of exposure were estimated at some $350 million between 2013-2014, down from c. $3 billion in 2003-2004 in the US alone from reduced exposure to PFOA. The costs identified are based on IQ deficits as well as hospitalisation costs. The reduction observed was consistent with industry initiatives, led by a prominent producer, from 2002 alongside a stewardship programme launched by the United States Environmental Protection Agency (US EPA) in 2006, to reduce and then phase out the use of PFOA (Malits et al., 2018). The European Commission submitted a proposal to list PFOA on the Stockholm Convention in 2015.[12]

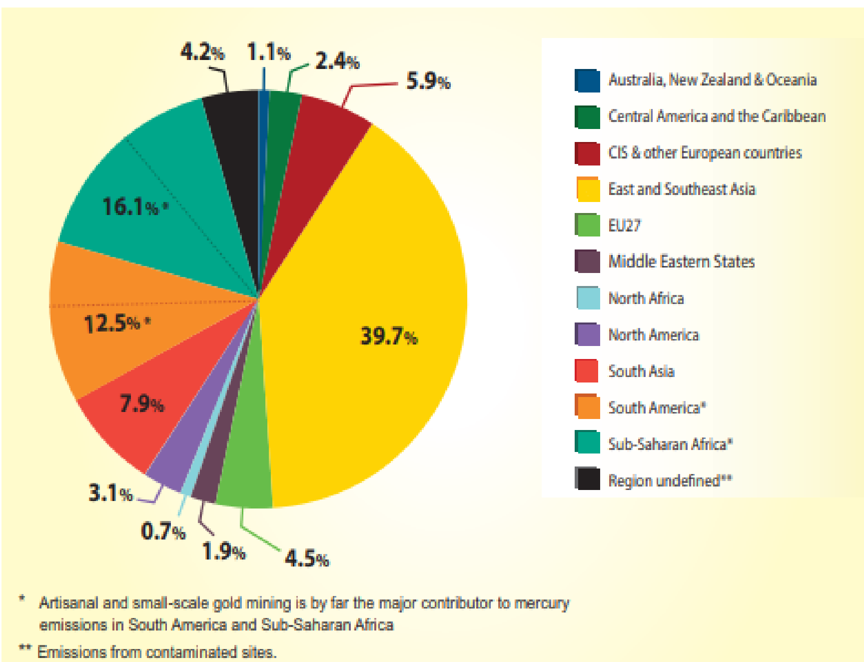
[11] http://chm.pops.int/TheConvention/Overview/tabid/3351/Default.aspx

[12] http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC11/Overview/tabid/4558/mctl/ViewDetails/EventModID/871/EventID/553/xmid/13837/Default.aspx

In January 2013, negotiations were concluded on a global treaty to protect human health and the environment from the adverse effects of mercury. The "Minamata Convention on Mercury" (MC) was named after the Japanese town that experienced severe methylmercury pollution in the 1950s.

The benefits of the MC were estimated by Bellanger et al. (2013). Avoided developmental impacts from prenatal exposure was associated with the loss of around 600,000 IQ points per year in Europe alone, corresponding to a total economic benefit from removing methylmercury of around €9 billion per year, again in Europe alone. This indicated global benefits of prevention upwards of c. €17 billion ($20 billion). A US study found that global action via the MC may double the benefits of domestic US action by 2050 (Giang and Selin 2016). A regional breakdown of global mercury emissions illustrating the global nature of the issue is below.

Figure 5: Regional Mercury Emissions in 2010



Source: UNEP (2013) http://cwm.unitar.org/cwmplatformscms/site/assets/files/1254/mercury_timetoact.pdf

5.1.2 Benefits of action - United States

The US EPA publishes extensive data and assessment tools on the economic costs and benefits of environmental regulation[13]. The US Office of Management and Budget also publish annual reports evaluating the costs and benefits of all federal regulation. The 2016 report, the latest available version, concludes that benefits of US EPA regulation to the US economy far outweigh the costs. The benefit/cost ratio of US EPA regulations are amongst the highest of all federal regulation[14]. The report

[13] https://www.epa.gov/regulatory-information-topic/regulatory-information-topic-toxic-substances

[14] See: 2016 Draft Report to Congress on the Benefits and Costs and Federal Regulations and Agency Compliance with the Unfunded Mandates Reform Act, Office of Management and Budget 2016 https://obamawhitehouse.archives.gov/sites/default/files/omb/assets/legislative_reports/draft_2016_cost_benefit_report_12_14_2016_2.pdf

also sets out various recommendations to improve and encourage greater retrospective regulatory review[15].

The US EPA is legally required to evaluate how "overall health, welfare, ecological, and economic benefits of the Clean Air Act programs compare to the costs of these programs". These have been evaluated in one retrospective study (1970-1990) and two prospective studies (1990 - 2010 and 2010-2020). The retrospective study compared actual implementation, based on historical data, with a hypothetical assumption that no further action was taken beyond 1970. Later studies evaluated prospective benefits based on forecasts and on amendments to that original act.

The scope of the early study included emissions of and effects from SO_2, NO_X, particulate matter, VOCs, lead, ground level and stratospheric ozone and ambient air quality (see the related discussion in Box 4). Later studies broadly retained these categories, but some new ones were included as methods improved. Health effects assessed included: premature mortality, lost IQ points, hypertension, coronary heart diseases; hospital admissions; respiratory related ailments, asthma attacks and restricted activity days. The first review noted substantial emission reductions had been achieved during a period of strong population growth (22%) and economic growth (70%). Key findings from the first and latest studies are:

- **Benefits of action (Retrospective 1970-1990):** The total monetised benefits of the Clean Air Act realised between 1970 and 1990 were estimated at just over $20 trillion (central estimate). This compared to direct costs of approximately $0.5 trillion dollars[16] [17].

- **Benefits of action (Prospective 1990- 2020):** The most recent study estimated that annual benefits would grow over time as emissions control programs take full effect, reaching a level of approximately $2 trillion in 2020. This compared to estimated costs of some $65 billion in the same year. Most of the monetary benefits reflect the approximately 230,000 cases of premature mortality expected to be avoided. Preventing premature mortality associated with ozone exposure; preventing morbidity, improving the quality of ecological resources and improved visibility are also significant[18]. The authors' concluded:

"it is extremely unlikely that the monetized benefits over the 1990 to 2020 period reasonably could be less than its costs, under any alternative set of assumptions we can conceive. Our central benefits estimate exceeds costs by a factor of more than 30 to one, and the high benefits estimate exceeds costs by 90 times. Even the low benefits estimate exceeds costs by about three to one".

(US EPA 2011)

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[15] See pages 50-52. These include formal requirements for periodic review when adopting regulations with significant uncertainties, planning for data collection for the purposes of review when drafting/adopting regulation, greater use of pilot projects and of third party evaluation.

[16] https://www.epa.gov/sites/production/files/2015-06/documents/contsetc.pdf

[17] Note a first prospective study evaluated the benefits of action between 1990-2010. Importantly this evaluated the incremental effects over and above those identified in the first study. It concluded the net benefit (benefits minus costs) over the 1990 to 2010 period of the additional criteria pollutant control programs incorporated in the Post-CAAA was some $510 billion. Some four times the costs. See: https://www.epa.gov/sites/production/files/2015-07/documents/fullrept.pdf

[18] US EPA 2011, The Benefits and Costs of the Clean Air Act from 1990 to 2020 Final Report U.S. Environmental Protection Agency Office of Air and Radiation https://www.epa.gov/sites/production/files/2015-07/documents/fullreport_rev_a.pdf

Similarly, in January 2018 the Canadian Government published proposals for further controls to eliminate asbestos. Using break even analysis the impact assessment explored the numbers of avoided cases of lung cancer or mesothelioma required to meet the expected costs (Government of Canada 2018). Such analyses are common for specific acts within various regulatory jurisdictions around the world – only a small number of which can be covered here.

5.1.3 Benefits of action – Europe

5.1.3.1 *Benefits of action from late 1960s from European chemicals policy resulted in avoided damage valued in "high tens of billions of Euro" per year.*

It is important to carefully evaluate what action taken to date has achieved as a basis for future action. Research published in 2017 explored how a wide range of regulatory (and voluntary) action taken in the European Union has reduced the cumulative costs associated with several chemical exposures since the late 1960s, avoiding/reducing health and environmental damage and the associated costs.

The approach used in this study was based on a triangulation of: substance specific data (e.g. data on emissions of heavy metals/arsenic or VOCs and on concentration of chemical substances in blood hair, breast milk or urine (biomarkers); of analysis on the effects of specific regulations (for example REACH[19]); and evidence which relates to specific end points (e.g. the overall rate of cancers), drawing out, where possible, the role of chemical exposure compared to other factors. Several specific case studies were developed – where biomarker data and dose-response data were available. These estimated likely physical effects avoided and the monetary value of these, over time. Whilst precise numbers are uncertain, the authors consider the overall magnitude of effects to be robust.

In this study the monetary value of identified effects are conservatively estimated in the "high tens of billions of Euro, per year". Whilst analyses have not yet captured possible effects from multiple exposures or of so-called regrettable substitution, as methods for valuation of effects on environmental end points are improved and as more data becomes available, the quantifiable value of benefits of reduced exposure from regulated chemicals may increase, perhaps significantly (Amec Foster Wheeler, 2017a). Tables 5 and 6 summarise the results.

Table 5: Selected benefits of European action (1960-2000s) – Human health

	Physical benefits (i.e. number of cases avoided)	*Period assessed*	*What is the nature and monetary value of benefit identified?*	*Important regulatory action*
Cancers	• *Total avoided cancer deaths in the order of 1.4 million (from 13 carcinogens)*	• *1995-2015*	• *Not quantified.*	• *Carcinogens and mutagens directive.*
	• *50-100 avoided deaths from hexavalent chromium exposure*	• *1995-2010*	• *€4 billion (€100m per year) based on VoSL (WTP).*	• *REACH.*
	• *175 avoided cancer cases from Benzene exposure*	• *1999-2008*	• *€0.7 – 0.9 billion (€60m per year) based on VoSL (WTP).*	• *Fuel Quality Directive.*
Neurodevelopment	• *Avoided IQ loss*	• *1976-2010*	• *€200 billion on average per year. Avoided impairment of productivity and lost lifetime earnings.*	

[19] See for example ECHA (2017b), https://echa.europa.eu/documents/10162/13630/cost_benefit_assessment_en.pdf

	Physical benefits (i.e. number of cases avoided)	Period assessed	What is the nature and monetary value of benefit identified?	Important regulatory action
	• *Avoided cases of mild mental retardation (MMR)*	• *1976-2010*	• *€250 billion, on average, per year. Measured in DALYS (WTP).*	• *Various action on lead, especially lead in fuel.*
Cardiovascular and respiratory diseases	• *Avoided cases of hypertension (high blood pressure)*	• *1990-2015*	• *Up to €75 billion per year. Measured in DALYS (WTP) (particular uncertainty noted by authors).*	
	• *Reduced asthma levels*	• *2004-2013*	• *€250 million per year (based on direct health care costs, avoided lost productivity and WTP values).*	• *Various, including REACH and CLP.*
Reproductive health	• *Female reproductive health (reduced cases of endometriosis associated with phthalate DEHP)*	• *1996-2008*	• *€7 billion based on healthcare costs and avoided productivity loss.*	• *Various sectoral and substance specific legislation (cosmetics, food contact, REACH, CLP, action on PCBs, PCTs).*
	• *Male reproductive health (reduced infertility associated with phthalate DBP)*	• *1996-2008*	• *€7 billion based on assistant reproductive technology (ART) treatment.*	
Blood, skin and bones	• *Avoided occupational skin diseases*	• *2004-2013*	• *€2 billion (c. €200 m on average per year). Based on treatment/diagnostic costs, productivity savings and WTP values.*	• *REACH and CLP.*

Source: Based on Amec Foster Wheeler 2017a. VoSL denotes "value of statistical life and WTP – denotes "willingness to pay" as the method used to elicit valuation.

Similarly, studies published by the European Chemicals Agency (ECHA 2016a and ECHA 2016b) evaluated the economic costs and benefits from a selection of restrictions and applications for authorisation, taken under the REACH regulation, respectively. Taking each in turn:

- The economic costs of the restrictions – for all cases reviewed and where data was available - amounted to €290 million per year, in total. The identified benefits, which could be identified in only a small number of cases, were in the order of some €700 million per year[20].
- A similar review of around 100 applications for authorisation indicated that whilst all applications were ultimately granted, identified risks were managed via additional requirements and/or monitoring in two thirds of uses and shorter periods of permitted use than those requested by applicants.

5.1.3.2 *Benefits of action on environmental conditions from chemicals legislation are evident, but it is much harder to quantify and to attribute monetary values to environmental effects*

The environmental impacts (effects on animal and plant life, on water, and on contaminated land) were assessed in the same study (Amec Foster Wheeler 2017a) over the same period. Here, the challenges of attributing benefits to specific actions, of aggregating values and the extent of data gaps are greater. Only partial monetisation of the benefits identified was possible and for a limited number of specific substances and/or locations. The wide ranges of these estimates reflect generally greater uncertainty and in some cases these are based on extrapolation. But because of the greater uncertainties and lack of comparable quantitative methods to those used for health impacts, there is a risk that environmental effects are overlooked in the development and assessment of policy and that "early warnings" of environmental damage arising from chemical pollution are missed.

[20] Note that the results of the Amec Foster Wheeler 2017a study summarised above, drew on this research, particularly the section on "blood, skin and bones".

Environmental benefits identified in the EU arising from regulatory or voluntary action included:

- Reductions in chemicals found in water which was used for domestic, agricultural and industrial purposes;
- Evidence of some recoveries in fish populations and their reproductive capacity;
- Avoided damage to biodiversity and ecosystem services; alongside protection of recreational activities/aesthetic values;
- Avoided damage to bird and insect life and avoided contamination of land and soil, over periods consistent with regulatory action.

A small number of case studies, where quantified estimates could be derived are summarised in Table 6. Many more issues were discussed qualitatively and hence are less amenable to inclusion in summary analyses.

Table 6: Selected benefits of European action (1960-2000s) – Environment

	Physical effects	Period assessed	Nature and monetary value of benefit	Important regulatory action
Water Quality	• *Lower water treatment costs from reduced pesticides in drinking water.*	• *2015 estimate*	• *€0.5 billion per year, arising from lower treatment costs to remove pesticides in waste water treatment plants (WWTP).*	• *Water Framework Directive (WFD), Marine Strategy Framework Directive (MSFD), Drinking Water Directive, Environmental Quality Standard (EQS) Directive.*
	• *Increased fish population and improved nutrient cycling from lower TBT concentrations.*	• *2006 estimate*	• *From €0.1 billion up to c. €100 billion per year from increased commercial fishing revenues and improved nutrient recycling based on WTP values. Noted as highly uncertain.*	
Birds and bees	• *Pesticides regulation.*	• *2009 estimate*	• *€15 billion to €50 billion per year. Estimated benefit per household. Uncertain – based on extrapolation.*	• *Directive on Plant Protection Products* • *WFD* • *Stockholm Convention on POPs.*
	• *Benefits to health of bird population from ban on DDT. Recovery of sparrow hawk population.*	• *2006 estimate*	• *€4 million to €12 million per year, based on WTP for recreation values.*	
Contaminated land	• *Avoided damage from lower volumes of PCB containing waste.*	• *2006 - 2014*	• *Avoided clean up and decontamination costs of €180 million per year.*	• *Directive on disposal of PCB/PCTs (and several earlier restrictions)* • *Stockholm Convention on POPs.*

Source: Based on Amec Foster Wheeler 2017a. "WWTP" denotes Waste Water Treatment plants. TBT is Tributyltin (a biocide) "WTP" – denotes "willingness to pay" as the method used to elicit valuation. DDT = dichlorodiphenyltrichloroethelene (an insecticide). PCBs are polychlorinated biphenyls.

5.2 Conclusions and challenges – benefits of action

The role of economic analysis in retrospective public policy evaluation is to ensure that scarce resources are allocated effectively, that policy outcomes are well targeted, delivered at least cost and that lessons from success and failure are reflected in future action. Quantitatively assessing the effects of chemical regulation is methodologically challenging. Developing a plausible counter-factual (i.e. what would have happened with no/different action) and attributing observed changes to specific action remain particular challenges. Despite this, there is a surprising lack of *ex-post* evidence. Too much is *ex-ante*, essentially assuming rather than verifying benefits (and costs) even some time after action has been taken.

Whilst progress is noted[21] assessment of effects does not appear to be aligned with that of the enforcement of chemical regulation. Many health outcomes associated with chemical exposure (alongside multiple other factors) such as the overall incidence rates for several cancers, appear to be getting worse. The risks from many chemicals are not fully understood. Drawing thematic conclusions from existing analysis is difficult due to differences in method, scoping, time periods assessed as well as differences in unit cost and valuation assumptions used.

The OECD considered these issues in a 2017 paper (Dudley 2017), proposing a series of actions and recommendations. These include:

- Greater planning for retrospective review at the outset, alongside greater incentives for it;
- Improved assessment of causal relationships, both from increased use of statistical tools, greater *ex-post* testing of *ex-ante* hypotheses and staggered/variable implementation to enable meaningful counterfactual scenarios;
- Greater consideration of both unintended consequences and of the interaction between multiple regulations[22];
- Consider thematic, rather than regulation specific, evaluation of policy and greater use of independent review;
- Providing meaningful opportunities for public engagement.

6 The economic costs of inaction

This section explores published analysis on the economic costs to health and the environment of inaction. This involves delving into progressively more detailed data that aim to better reflect the role of chemical exposure. First, we review global estimates on the extent of the health burden from non-communicable diseases generally. This provides context and shows trends. Next, analysis on the extent to which these costs can be attributed to the external environment (so called environmental effects) are examined. Finally, more specific data on the role that chemical exposure plays within these environmentally attributed effects are explored. Economic estimates of the costs of inaction from specific chemical exposures are then set out. Finally, available analysis on other liabilities that may arise from chemical use, including on businesses, are summarised.

6.1 Economic costs of inaction - Global estimates

6.1.1 What is the extent of the problem?

The most authoritative and detailed information on the global public health burden from major diseases and risk factors is contained in the Global Burden of Disease (GBD) series of analysis. As noted earlier, there are two such sources; from the World Health Organisation (WHO) and from the Institute for

[21] In 2015 the European Commission carried out a study for the development of a series of potential enforcement indicators for REACH and CLP http://ec.europa.eu/growth/content/measuring-reach-and-clp-enforcement-new-study-0_bg

[22] In a related field, the Environmental Impact Assessment (EIA) Directive explicitly requires assessment of cumulative (I.e. in combination) effects, for example. The EIA Directive (85/337/EEC): http://ec.europa.eu/environment/eia/eia-legalcontext.htm

Health Metrics and Evaluation (IHME), an independent research centre at the University of Washington[23].

6.1.1.1 *The WHO data*

Deaths from all causes covered in the study decreased between 2000 (56.8 million) and 2016 (52.3 million). But deaths from non-communicable (i.e. largely preventable, non-infectious or transmissible) diseases have increased over the same time period between 2000 (31.6 million) and 2016 (40.5 million) [24]. The most common causes include cardiovascular diseases (31.4% of all deaths); "malignant neoplasms" (i.e. cancerous tumors) (15.8%); and respiratory diseases (6.7%)[25]. DALYs from all causes have increased somewhat between 2000 (2.7 billion) and 2015 (2.8 billion). DALYs from non-communicable diseases are also increasing; some 1.5 billion in 2015, up from 1.3 billion in 2000. Similarly, non-communicable disease years of life lost (YLLs) are increasing (982 million in 2015 up from 844 million in 2000)[26].

6.1.1.2 *The IHME data*

The slightly more recent IHME data show similar data, some 39.5 million deaths in 2016; just under 1.5 billion DALYs and 820 million YLLs[27]. Non-communicable disease trend data below show steady increases since 1990, (see Figure 6).

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[23] http://www.healthdata.org/

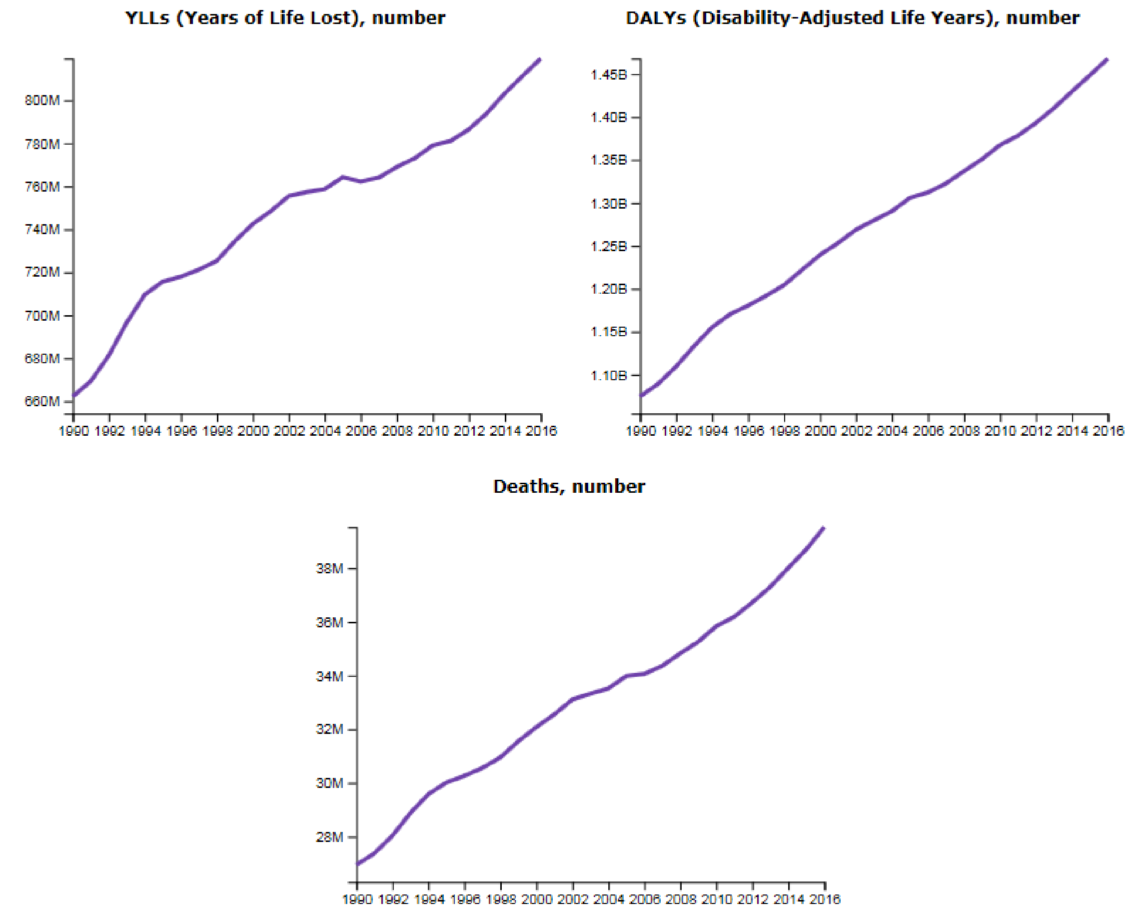
[24] http://www.euro.who.int/en/health-topics/noncommunicable-diseases/ncd-background-information/what-are-noncommunicable-diseases

[25] Global Health Estimates 2016: Deaths by Cause, Age, Sex, by Country and by Region, 2000-2016. Geneva, World Health Organization. http://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html

[26] Global Health Estimates 2016: Deaths by Cause, Age, Sex, by Country and by Region, 2000-2016. Geneva, World Health Organization. http://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html Global Health Estimates 2015: Disease burden by Cause, Age, Sex, by Country and by Region, 2000-2015. Geneva, World Health Organization; 2016. http://www.who.int/healthinfo/global_burden_disease/estimates/en/index2.html

[27] Global Burden of Disease Study 2016 (GBD 2016) Data Resources http://ghdx.healthdata.org/gbd-results-tool

Figure 6: IHME Non-communicable diseases – trends (1990 – 2016)



Global Burden of disease study, 2016 (GBD 2016). *http://ghdx.healthdata.org/gbd-results-tool?params=gbd-api-2016-production/52cac17c77a85b28f7856c8b5d62995e*

6.1.1.3 *To what extent is this attributable to the external environment and to exposure to harmful chemicals?*

Not all of the above damage is attributed to chemical pollution. In 2016 the WHO published a study evaluating the extent of *environmentally* attributable diseases (i.e. attributed to unhealthy environments) globally (Pruss-Ustun et al. 2016)[28]. It concluded that some 12.6 million deaths (23% of all deaths) were attributable to a range of – avoidable – environmental factors. The equivalent proportion of DALYs is 22% (596 million), based on 2012 data. Over a quarter of deaths of children under 5 years old could be avoided if environmental risks were removed. Whilst total deaths attributed to the external environment have remained stable, more are now attributed to non-communicable diseases (data relates to 2002-2012). Of 133 diseases, 101 had significant links with the environment. Of these, several non-communicable diseases, including cancers; mental, behavioural and neurological disorders; cataracts; cardiovascular diseases; chronic obstructive pulmonary diseases; asthma; and congenital

[28] The environment is the congregation of "all the physical, chemical and biological factors external to a person and all related behaviours, but excluding those natural environments that cannot reasonably be modified". This definition excludes behaviour not related to the environment as well as behaviour related to the social and cultural environment, genetics and parts of the natural environment". Page 3.

anomalies were associated with either indoor or ambient air pollution, UV radiation, occupational exposure and exposure to "chemicals" (further specific estimates were attributable to lead). Specific population attributable fractions (PAFs) of DALYs were identified for various diseases and by risk factor[29]. Table 7 below highlights those associated with chemical exposure. The review also highlighted several important factors when assessing the economic costs of this exposure:

- On average the environmentally attributable fraction of DALYs for non-communicable diseases steadily increases with age – from less than 10% at age 5 to over 20% by age 65, before beginning to decline;
- Men – on average – are more affected than women and this applies to non-communicable as well as other types of diseases. This is possibly a reflection of poorer background health, or gender differences in occupations;
- Age standardised death rates from non-communicable diseases attributable to the environment are highest in low and middle-income countries, particularly Asia and South-East Asia, Sub Saharan Africa, Russia, parts of Eastern Europe and Latin America (Figure 7).

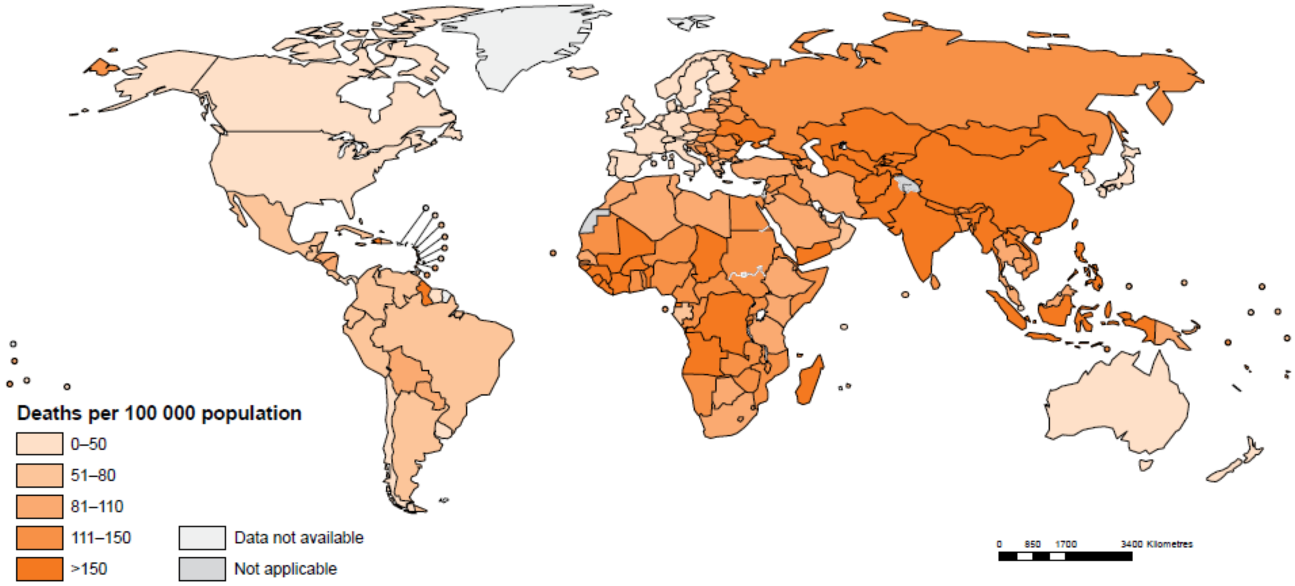
Table 7 Selected PAFs of DALYs **with known or suspected links to chemical exposure (non-additive)**

	Occupational risks	Ambient air pollution	Household air pollution	Lead
Lung cancer	7%	14%	17%	
COPD	12%	9%	24%	
Unintentional poisonings	14%			
Asthma	9%			
Acute lower respiratory infection		8%	33%	
Ischemic heart diseases		23%	18%	4%
Stroke		25%	26%	5%
Cataracts			24%	
Chronic kidney disease				4%

Source: Prüss-Üstün et al. (2016) and based on chemical disease associations from Amec Foster Wheeler (2017a).

[29] Further details of the methods applied are available in the report and here: http://www.who.int/quantifying_ehimpacts/summaryEBD_updated.pdf

Figure 7: Age standardized noncommunicable disease death rates attributable to the environment (2012)



Reproduced from Prüss-Üstün, et al., (2016). Page Xxi.

6.1.2 What are the global economic costs from environmental and chemical pollution?

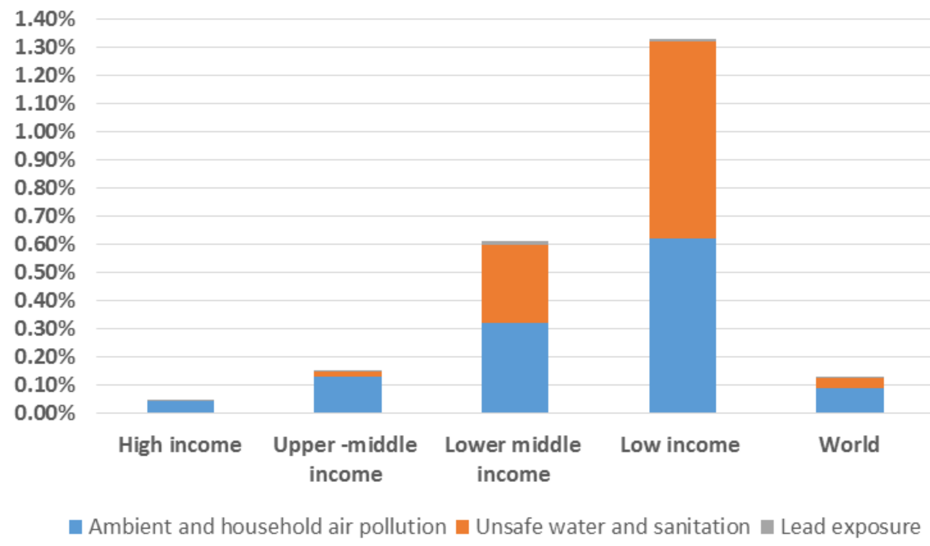
A global assessment of the extent of disease and death caused by pollution and its associated costs was carried out in 2017 by the Lancet Commission on pollution and health. This included assessment of human health effects from indoor and outdoor air pollution, from water pollution and from soil, heavy metal and chemicals pollution as well as occupational pollutants[30]. Chemical exposure plays a role in all of these effects, alongside other factors, so as with the previous data, this data reflects several risk factors beyond chemicals exposure. The economic costs were evaluated first in relation to economic productivity, then in relation to "welfare". Key data is reproduced from (Landrigan et al., 2017) and are shown in Figures 8-10.

In terms of economic productivity, losses are disproportionately high in low income countries. Pollution related diseases are estimated to reduce GDP in these countries by c.1.3% per year (up to c.1.9% if different discount rates are used). The primary causes quantified are water/sanitation as well as air pollution.

These losses decrease - as a proportion of GDP - in higher income countries, where the role of water sanitation decreases and that of air pollution increases. However, the absolute costs remain significant; some $53 billion in upper middle and high-income countries in 2015.

[30] Air pollution was defined as household air pollution, ambient fine particulate pollution (PM. 2.5) and tropospheric ozone pollution. Water pollution was defined as: unsafe sanitation and unsafe water sources. Soil, chemicals and heavy metal pollution was defined as: lead, including contaminated sites polluted by lead from battery recycling operations, and mercury from gold mining. Occupational pollution was defined as: occupational carcinogens and occupational particulates, gases and fumes.

Figure 8: Productivity losses as a percentage of gross domestic product (GDP) by World Bank income group (2015) (%)



Source: Reproduced from Landrigan et al. (2017). Based on productivity losses from pollution related deaths as a percentage of GDP.

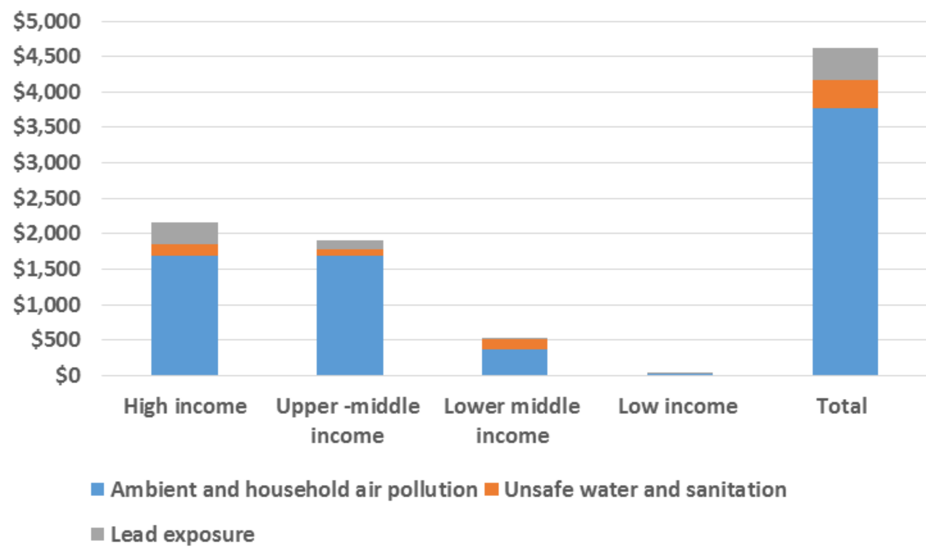
At the same time – and in addition - pollution related diseases are estimated to account for up to 7% of annual health spending in middle income countries and 1.7% in high income countries. This data is not available for low income countries.

In terms of losses to individual welfare[31] the values greater still – equivalent to just under $5 trillion globally in 2015. Figures 9 and 10 illustrate these data, first absolutely, by showing total values and then relatively, in terms of the proportion of total gross national income (GNI). These illustrate that, whilst absolute values are significantly greater in high income countries – reflecting higher earnings - the relative individual valuation of good health is more equal.

The Lancet Commission analysis usefully evaluates the global health burden caused by pollution using a consistent method. The data relates to a range of environmental factors, chemical exposure is only part of this but the analysis illustrates the global scale of the overall problem and its distribution. Importantly, whilst a small proportion of the costs are directly attributed to lead, various other chemical effect pairings aren't considered. The economic costs do not account for damage to ecosystems and biodiversity. Quantified effects on economic productivity exclude indirect effects as well as effects on the old. The estimates are based only on well characterised health effects from well-studied sources of pollution (zone one of the "pollutome"). It assumes economic costs from all other sources of pollution (zones two and three in the "pollutome") are zero and understates subclinical effects.

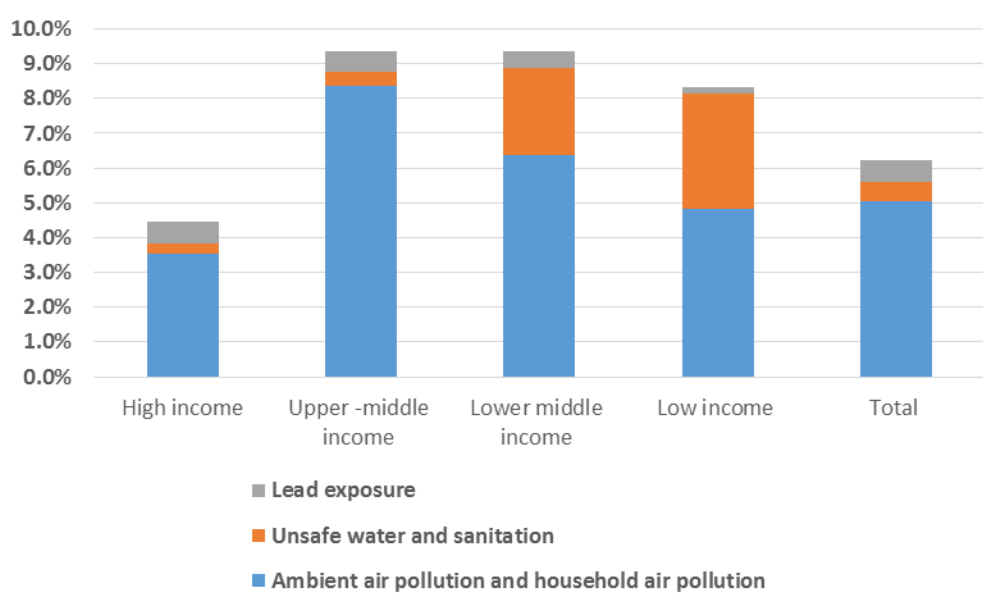
[31] Welfare losses from pollution related diseases are defined as equal as household WTP to reduce pollution. The estimate above is derived from applying the Value of a statistical life (VSL) to premature deaths attributable to pollution (in 2015).

Figure 9: Welfare damages by World Bank country income group (2015). Billions of US $



Source: Reproduced from Landrigan et al. (2017). Based on Value of Statistical life (VSL) approach of premature deaths associated with pollution.

Figure 10: Welfare damages by World Bank country income group (2015). Proportion of gross national income (%)



Source: Landriganet al. (2017). Based on Values of Statistical life (VSL) approach of premature deaths associated with pollution.

The challenge is to move a wider range of chemical health effect relationships "up the pollutome" so they may be reflected in economic evaluation. The Lancet Commission makes several recommendations in this respect. First, more research is required to estimate the morbidity effects of pollution (including chemical pollution) which in turn requires valuing a greater range of end points. Second, additional work is required on the non-health benefits of reducing (chemical) pollution, such as education benefits from reduced illness in children, indirect effects on families/dependents as well as values of damage to ecosystems. Several articles published around the same time seek to address some of these challenges and it to these that we now turn.

6.1.3 Market and non-market costs of inaction from chemicals exposure could be as much as 10% of global GDP

A global assessment of the disease burden from environmental exposure to chemicals was made in 2017 (Grandjean and Bellanger 2017). This was an attempt to address some of the drawbacks noted above by reflecting both a broader set of risks from chemicals as well as a wider set of effects than has been included in global burden of disease (GBD) studies to date[32]. The authors acknowledged challenges in assessment of this kind but argued that DALY-based calculations are likely to significantly underestimate effects from chemical exposure, which may actually result in costs exceeding 10% of global GDP. It is, however, important to note that the effects evaluated and shown below are based on both market (i.e. productivity effects or health costs) and non-market effects (i.e. willingness to pay valuation) which should be born in mind when comparing the results to GDP directly. A future refinement of these estimates may usefully involve separating these effects. The debate over the underlying epidemiological evidence has been noted above.

Relationships between chemicals and adverse health (for example arsenic contaminated drinking water, endocrine disrupting chemicals (EDCs), as well as effects from lead and methylmercury on cognitive development), are not covered in GBD studies. To address this, the review combined available assessments of chemical exposure with economic values of environmentally-related health outcomes. These are compared to estimates derived from the GBD studies, where possible. The Grandjean and Bellanger (2017) findings are reproduced in Table 8, and key results are as follows. All values are per year and are in 2010 US dollars estimates unless specified:

- **Lead:** The "GBD report" identifies costs of $5 billion per year based on the costs of intellectual disability (i.e. mild mental retardation, defined as an IQ of below 70)[33]. But this does not include assessment of the economic effects of decreases in IQ losses within normal ranges (i.e. above 70). Several studies identified adverse effects on productivity, lifelong earnings as well as additional educational costs with incremental losses in IQ. Including these effects increases the estimated costs significantly, up to c.$1 trillion in low and middle-income countries alone and almost $2 trillion globally – equivalent to almost 2% of global GDP.
- **Methylmercury:** This is also associated with cognitive impairment and not included in the GBD study. Applying dose response data and exposure information – available only in the EU and the US - effects are estimated at just under $216 billion, per year based on a 2017 estimate. The global distribution of effects is unknown but is influenced by consumption of predatory fish among other factors.
- **Polybrominated diphenyl ethers (PBDEs) and organophosphate pesticides (OPs)** are also associated with cognitive impairment and with economic costs of just under $280 billion and $250 billion, in the EU and US respectively.

[32] See: https://www.thelancet.com/gbd

[33] It is not explicitly stated, but it is assumed this refers to the 2013 GBD assessment.

- **Air pollution:** Economic costs associated with air pollution based on DALYs are assessed at between $1.1 and $1.2 trillion. However, this excludes effects associated with pre-term birth/low birth weight, with asthma as well as cardiovascular risks.
- **Endocrine disruption:** These effects are not included in GBD studies. Using the Delphi technique, international working groups have identified a range of adverse health effects associated with these, concluding around >20% attribution of chemical exposures for effects including obesity, testicular cancer, infertility and mortality. Total costs from EDC exposure – again only in the US and the EU - was estimated at over $500 billion.

Table 8 Estimates of economic costs associated with different risk factors (2017)

Risk factor	Adverse consequences	Context	Economic cost ($billions, unless stated)	% GDP	% of Global GDP
Lead exposure	Cognitive deficits	LMICs	1040 [775.5–1237]	5.20 [3.9–6.2]	1.68 [1.25–1.99]
		U.S.	54.0 [47.5–64.3]	0.37 [0.33–0.44]	0.09 [0.08–0.1]
		EU	60.6 [53.7–72.2]	0.36 [0.32–0.43]	0.1 [0.09–0.12]
		Total (sum)	1154 [876.7–1373.5]	2.47 [1.88–2.94]	1.83 [1.39–2.18]
	Intellectual disability only	World (WHO)	16 [10–40]	<0.01	<0.01
		World (GDB)	246 [154–615]	0.4 [0.24–1]	0.4 [0.24–1]
	Neurotoxicity total	World (WHO)	5 [3.15–12.6]	<0.01	<0.01
		World (GBD)	283 [177–708]	0.45 [0.27–1.1]	0.45 [0.27–1.1]
Methylmercury	Cognitive deficits	U.S.	4·8 [4.2–5.7]	0.03 [0.026–0.04]	<0.01
		EU	10.8 [9,6–11.2]	0.06 [0.053–0.062]	<0.01
		Sum	15.6 [13.8–16.9]	0.05 [0.044–0.54]	<0.01
Organophosphate pesticides	Cognitive deficits	U.S.	44.7 [14.6–59.5]	0.30 [0.1–0.4]	0.07 [0.2–0.09]
		EU	194 [62–259]	1.14 [0.37–1.52]	0.31 [0.09–0.4]
		Sum	248.7 [76.6–318.5]	0.8 [0.25–1.02]	0.38 [0.11–0.49]
Polybrominated diphenyl ethers	Cognitive deficits	U.S.	266 [133–367]	1.8 [0.9–2.5]	0.4 [0.2–0.6]
		EU	12·6 [2.08–29.4]	0.07 [0.011–0.16]	0.02 [0.003–0.05]
		Sum	278.6 [135.08–396.4]	0.9 [0.43–1.28]	0.42 [0.23–0.6
Air pollution	Asthma	U.S.	2.33 [0.728–2.5]	0.02 [0.006–0.021]	<0.01
		EU	1.70 [0.568–1.98]	0.01 [0.003–0.012]	<0.01
		EU city children [97]	0.151 [0.03–0.3][a]	<0.01	<0.01
	Preterm birth	U.S.	4.3 [2.06–8.22]	<0.01	<0.01
	Cardiovascular	EU	37.24 [24.47–49.83][a]	0.22 [0.14–0.29]	0.06
	All health impacts	OECD countries [100]	500 [300–1250]	1.2 [0.7–2.8]	0.8 [0.5–2]
		China	483 [300–1200]	8 [5–20]	0.8 [0.5–2]
		India	120 [74–300]	7 [4–17]	0.2 [0.1–5]
		Sum (OECD, China, India)	1100 [700–2760]	2.2 [1.3–5.4]	1.8 [1.1–4.4]
		World (WHO)	1177 [736–2942]	1.9 [1.1–4.6]	1.9 [1.1–4.6]
		World (GBD)	1083 [677–2709]	1.7 [1.1–4.3]	1.7 [1.1–4.3]
EDCs			Economic cost - ($millions)		
Polybrominated diphenyl ethers (PBDEs)	Testicular cancer	US	81.5 [24.8–109.3]	<0.01	<0.01
		EU	1100 [416–1100]	<0.01	<0.01
	Cryptorchidism	US	35.7 [NA - NA]	<0.01	<0.01
		EU	172.6 [155.5–172.6]	<0.01	<0.01
Dichlorodiphenyl trichloroethane (DDE)	Childhood obesity	US	29.6 [NA - 57.3]	<0.01	<0.01
		EU	32.7 [NA - 114.8]	<0.01	<0.01
	Adult diabetes	US	1800 [NA – 13,500]	<0.01 [NA - 0.08]	<0.01
		EU	1100 [NA – 22,065]	<0.01 [NA - 0.13]	<0.01
	Fibroids	US	259 [NA - NA]	<0.01	<0.01
		EU	216.8 [NA - NA]	<0.01	<0.01
	Adult obesity	US	1700 [NA - NA]	0.011	<0.01

Risk factor	Adverse consequences	Context	Economic cost ($billions, unless stated)	% GDP	% of Global GDP
Di-2-ethylhexyl phthalate		EU	20,800 [NA - NA]	0.12	<0.01
	Adult diabetes	US	91.4 [NA - NA]	<0.01	<0.01
		EU	807.2 [NA - NA]	<0.01	<0.01
	Endometriosis	US	47,000 [NA - NA]	0.32	<0.01
		EU	1700 [NA - NA]	0.01	<0.01
Bisphenol A	Childhood obesity	US	2400 [NA - NA]	0.02	<0.01
		EU	2000 [NA - NA]	0.02	<0.01
Benzyphtalates & butylphtalates	Male infertility resulting in Increased ART	US	2500 [NA - NA]	0.02	<0.01
		EU	6300 [NA - NA]	0.04	0.01
Phthalates	Low testosterone and increased early mortality	US	8800 [NA - NA]	0.06	0.012
		EU	10,600 [NA - NA]	0.05	0.012
Multiple exposures	Attention deficit hyperactivity disorder (ADHD)	US	698 [568–1950]	<0.01 [<0.01–0.011]	<0.01
		EU	3056 [1600–3800]	0.014 [<0.01–0.017]	<0.01
	Autism	US	1984 [803–4100]	0.014 [<0.01–0.024]	<0.01
		EU	352 [105–530]	<0.01	<0.01
All compounds included		US	340,000 [668–612,000]	2.33 [<0.01–3.53]	0.54 [<0.01 0.96]
		EU	217,000 [110,049–359,239]	1.2 [0.75–2.12]	0.34 [0.17–0.57]
		Sum	557,000 [110,707–971,239]	1.8 [0.3–3.07]	0.88 [0.17–1.54

Source: Grandjean and Bellanger (2017) Note this table combines the data in four tables in the underlying study. Base case estimates are presented along with range (low/high end estimates from sensitivity analysis. All estimates are given in 2010 US Dollars.

6.1.4 Estimates suggest public health costs from endocrine disrupting chemicals are globally significant

Several other recent studies focus on costs arising from exposure to EDCs, using similar methods. These were published in the context of active European regulatory decision making on EDCs[34]. Again the primary aim was to attempt to address the underestimation of economic costs associated with exposure. As above, these focus on European and US exposure only and on EDCs where the authors judge sufficient epidemiological studies exist. Whilst the strength of evidence and probability of causation differed – and have caused debate - the effects judged by the authors to have probable causation include IQ loss; autism; attention deficit hyperactivity disorder (ADHD); endometriosis; fibroids; childhood obesity; adult obesity; adult diabetes; cryptorchidism; male infertility, and mortality associated with reduced testosterone (Trasande et al. 2016). Chemicals which include polychlorinated biphenyls (PCBs), OPs and pesticides amongst others are associated with these effects which can cause lifelong direct and indirect economic effects (Bellanger et al. 2015).

These studies suggest that the costs of inaction in the order of hundreds of billions (results are in both dollar and Euro) per year. The values are lower than estimated in the Grandjean and Bellanger (2017) study above but are in similar orders of magnitude given the range of effects considered are narrower. The key conclusions, though not without uncertainties, debate and data gaps, illustrate significant economic costs from ongoing exposure to chemicals. Several of these studies applied a weight of evidence characterisation approach, adapted from that used by the Intergovernmental Panel on Climate Change (IPCC). The scale and nature of economic effects identified in these papers are summarised below.

[34] See: http://ec.europa.eu/environment/chemicals/endocrine/index_en.htm

- **Neurobehavioral deficits in the EU** include IQ loss (including intellectual disability – or mild mental retardation); attention deficit-hyperactivity disorder (ADHD) and autism spectrum disorder (ASD). Exposure to PBDEs, OPs and phthalates, considered by the authors to be amongst the best documented relationships, were assessed. The overall economic costs of this exposure was estimated in 2010 at c. €150 billion per year in the EU alone. Of this some €10 billion was attributed to PBDEs, just under €50 billion to OPs, €0.8 billion to ASD and €2.4 billion to ADHD. The study was not able to explore the effects from multiple exposures to chemicals, the so-called cocktail effect (Bellanger et al. 2015).

- The **costs of male reproductive disorders and diseases in the EU** attributed to EDCs were estimated at up to €15 billion per year in 2010. The costs comprise some €4.7 billion from assisted reproductive treatments (ARTs) and just under €8 billion from lost economic productivity and deaths from lower testosterone concentrations – both attributed to phthalate exposure; and €130 million from cryptorchidism associated with PDBE exposure. Although comparatively less certain, the costs from testicular cancer associated with PDBE exposure are estimated at some €0.8 billion. All costs are per year and 2010 estimates (Hauser et al. 2015).

- Similar conclusions were drawn regarding **female reproductive disorders in the EU**, with costs estimated at €1.5 billion per year in 2010. These comprised diphenyldichloroethene (DDE) attributable fibroids (estimates based on the cost of treatment) and phthalate attributable endometriosis (with estimates based on direct medical costs and lost productivity). It should be noted that the probability of causation was somewhat lower in this case than those above. (Hunt et al. 2016).

- **Obesity and diabetes** are also attributed to EDC exposure. Costs associated with a total of five exposure effect relationships were estimated to result in costs in the order of €18 billion per year in 2010. This comprised some €16 billion from phthalate attributed adult obesity; €0.6 billion from phthalate attributed adult diabetes and some €1.5 billion from BPA attributed childhood obesity. A further €0.02 billion costs were associated with childhood obesity from DDE; and some €0.8 billion for DDE associated adult diabetes (Legler et al. 2015).

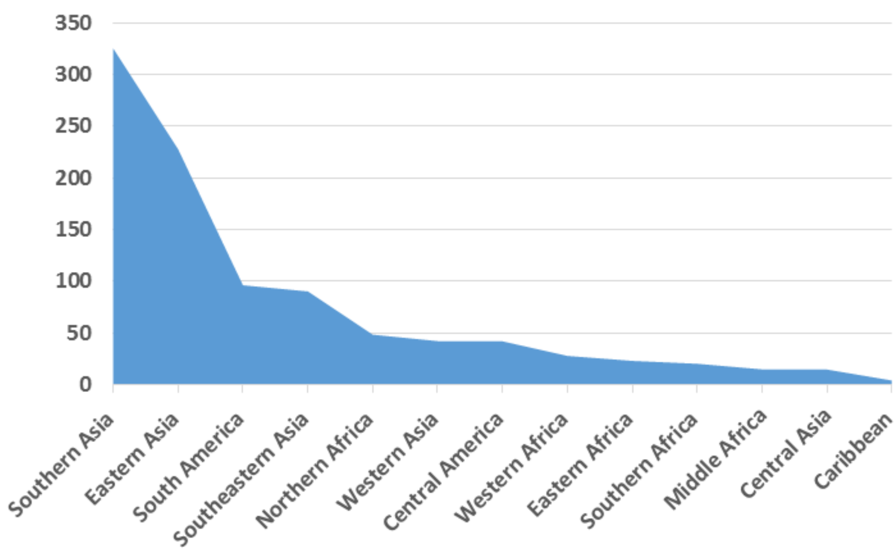
Two studies published in 2016 evaluated the cost burden from all effects above. These suggest costs – after accounting for probability of causation - in the EU alone of some €157 billion (Trasande et al. 2015) later updated to €163 billion per year – 1.28% of EU Gross Domestic Product (Trasande et al. 2016a). Other estimates put the costs higher still (Rijk et al. 2016). These are somewhat lower than the sum of all studies above, but in the same order of magnitude.

6.1.5 Costs of inaction likely to be disproportionately felt in low and middle-income countries

Although still very limited, research has increasingly sought to establish the costs of inaction in low and middle income countries (LMICs). In the context of the UN's Minamata Convention on Mercury and using data on mercury levels in hair, effects on IQ, lost productivity and DALYs, from 15 sites in LMICs were valued at between $77 million and $130 million per year. These sites were selected based on several sources of mercury including chlor-alkali plants, coal fired power plants and non-ferrous metal smelting. A Pacific Island without industrial sites was included to evaluate global deposition. The economic costs were based on lost productivity and suggest larger losses may be identified through assessment of a wider range of sites and countries (Trasande et al. 2016b).

This built on earlier studies on the effects of childhood lead exposure in LMICs. Together these indicate that, despite extensive and successful regulatory action on lead in petrol, the largest burdens may now be borne in these countries, from sources including batteries, paint, water pipes and waste. As above, the costs are based on estimates of lifetime productivity losses associated with decreases in IQ. Total losses are estimated at up to c. $1 trillion (some 1% of global GDP) in lost lifetime economic productivity (LEP) in 2011. These comprise $135 billion in Africa (4% of GDP), $700 billion in Asia (c.2% of GDP) and $140 billion in Latin America and the Caribbean (2% of GDP) respectively (Attina and Trasande 2013). The results are further disaggregated by WHO sub-region below.

Figure 11: Lost lifetime earning potential for each cohort of children under 5 from childhood lead exposure (2011, $ billions)



Source: Attina and Trasande (2013).

6.1.5.1 *Low level exposure – even to well-studied and regulated chemicals - is an ongoing problem*

Exposure to some chemicals has decreased substantially; the most extensively studied are heavy metals – lead in particular. However, exposure remains from paints, water pipes and in waste (Trasande et al. 2013; Amec Foster Wheeler 2017a, b). Even low-level exposure to lead in the US has been associated with over 400,000 deaths per year from cardiovascular and ischemic heart disease. This estimate was about 10 times larger than an earlier estimate noted in the paper, which reflects new evidence associating cardiovascular diseases with concentrations of lead previously thought to be safe. Higher concentrations of lead in blood were found in older, less educated people who were more likely to be male, to smoke, to consume larger amounts of alcohol and to have less healthy diets. Low level exposure to lead remains an important but largely overlooked risk factor (Lanphear et al. 2018).

6.1.5.2 *Liabilities, compensation and reputation*

Limited analysis exists on the costs associated with liabilities that are incurred by specific companies and this is associated with a small number of incidents/accidents. This section provides a brief discussion of these, including fines, compensation pay-outs as well as costs associated with reputational damage.

6.1.5.2.1 Compensation

Where preventable health affects due to a specific chemical exposure are proved, the company responsible may be liable to pay compensation or a fine. This may represent a 'one-off' payment in response to a single incident, as well as ongoing 'legacy' costs borne by insurers.

A high-profile case involved the accidental leak of methyl isocyanate in Bhopal, India in 1984, which killed 3,800 people, causing significant morbidity and premature death for thousands more (Broughton 2005). The company responsible paid a total of $470 million in compensation. More recent examples involve substantial settlements and payouts.

In an analysis of internal company documents disclosed at trial, Shapira and Zingales (2017) evaluate the decision making processes of a company in the context of an environmental case. The authors' present analysis that regulatory intervention/fines and the costs associated with legal liability were insufficient deterrents to the business's management - based on expectations of delaying or avoiding paying damages and mitigating the effects of reputational damage. The authors contend that increased public disclosure of information may have reduced the risks and that a range of further actions are required to better align private and public interests in future.

Historical liabilities can pose an ongoing financial cost. A key example of this is the compensation payable to individuals exposed to asbestos (Box 4). Here compensation pay-outs continue despite extensive regulatory action. This may reflect several factors, including: continued exposure to 'historical' asbestos, found 'locked' in older buildings; the long latency period between exposure and onset of disease; and people living longer through treatment, hence requiring prolonged care.

Box 4: Ongoing liabilities from historical chemical use – Asbestos

Globally the WHO estimate that 107,000 deaths are caused by mesothelioma, asbestos related lung cancer and asbestosis. The trend data indicate that cases of asbestosis and mesothelioma continue to increase, reflecting historical exposure to asbestos, representing an important 'legacy' cost to companies. Some EU Member States and the USA established systems for the victims of past exposure to asbestos to claim compensation. Information on the status of asbestos related claims in the US and Europe has been collated by the Institute and Faculty of Actuaries[35]:

- **USA – Pay-outs for mesothelioma have been up to $20m per person. The total cost arising from all past, present, and future US asbestos claims has been estimated to be between $200bn and $275bn. To manage rising numbers of claims, the Judiciary Committee of the US Senate proposed setting up a trust fund to pay out asbestos compensation and to contain the huge associated legal costs.**

- **France – Claimants apply to le Fonds d'indemnisation des Victimes de l'amiante (FIVA Fund for Victims of Asbestos Exposure). Compensation from the fund for a 60-year-old of approximately €275,000 (£193,000) for mesothelioma and €90,000 to €110,000 (£63,000 to £77,000) for non-terminal cancer. The French Federation of Insurers (FFSA) estimated that 100,000 to 200,000 asbestos-related claims would be made between 2003 and 2023, with an ultimate cost of € 8 to 10 billion, shared between social security, employers and insurers (Salvatori et al., 2003).**

- **Netherlands – Claims are dependent on a 3-year statute of limitations. Mesothelioma claimants whose exposure took place less than 30 years prior to the claim, proceed through the Institute for Asbestos Victims (IAV) – average payments are about €50,000 (£35,000); Mesothelioma claimants whose exposure took place more than 30 years prior to the claim,**

[35] http://www.theactuary.com/archive/old-articles/part-3/asbestos-claims-in-europe/

proceed through the Government Asbestos Institute (GAI) – average payments are €17,700 (£12,500).

- **Germany** – Any worker who succumbs to an asbestos-related disease after exposure in Germany can claim from the state Berufsgenoßenschaften (occupational health) system. Since 1980 there have been 11,000 asbestos-related deaths in Germany.
- **Italy** – In Italy, asbestos claimants must notify INAIL (Istituto Nazionale di Assicurazione contro gli Infortuni sul Lavoro - Institute of National Insurance for Accidents at Work). INAIL assesses each case and then notifies the INPS (Italian state pension department). Typically, the increase in pension benefits is estimated by increasing the pension contribution for the period they were exposed to asbestos by 50%.
- **UK** – The Asbestos Working Party (AWP) estimates that the potential cost of UK asbestos-related claims falling to the UK insurance market for the period 2009 to 2050 could be around £11bn.[36] According to the TUC, average pay-outs for mesothelioma vary between £50,000 and £100,000. An analysis of newsletters produced by the London law firm Norton Rose showed average payments were £98,127 for mesothelioma and £57,726 for lung cancer.

6.1.5.2.2 Reputational risk

Loss of reputation for companies negatively associated with chemical pollution incidents may have economic implications, for example, associated with a fall in stock market value or decreases in product sales. In the wake of the 1984 Bhopal disaster (see above), the company involved suffered significant reputational damage, which resulted in plans to build additional chemical plants in other parts of India being significantly disrupted (Broughton 2005).

Statistical analysis by Makino (2016) used stock price data on the Japanese chemical industry alongside analysis of chemical accidents between 2005 to 2012. The authors suggest that whilst stock prices significantly decreased after incidents, the risks of such accidents are not reflected in share price valuation leading up to these. They argue that greater disclosure of environmental risk information by companies may incentivize investment in risk reduction as this would have a larger effect on perceptions of business performance and hence stock prices.

6.2 Conclusions and challenges – costs of inaction

Economic analysis helps identify the underlying tradeoffs inherent in environmental policy decisions. Its use has influenced the development and scope of regulatory and non-regulatory action. Accurate analysis requires several earlier inputs which themselves are subject to uncertainty and debate. These include information on substance - disease parings, specific dose response relationship data, and information on exposure – across populations and over time - before judgements can be made about the economic effects of these. All economic analysis is subject to uncertainty, incomplete, and subject to revision, reflecting methodological refinements and new data over time. Economic analysis involves important assumptions on timescales of effect, discount rates, uncertainty assessment/sensitivity analysis, unit costs and ultimately about the relationship between health, the environment, work, short and longer-term preferences. It is hard to aggregate conclusions over large areas and populations and hard to isolate and attribute causal relationships.

Recounting the challenges is important as much progress has been made over the last several years. There is mounting, improving more detailed analysis that ongoing chemicals exposure places substantial

[36] http://www.theactuary.com/archive/old-articles/part-6/general-insurance-3A-a-clearer-view-on-claims/

economic burdens on healthcare systems as well as undermining the productivity and capability of the workforce. These distribution of burdens within populations and across countries are material at national and global level. Whilst less than for human health, there is improving analysis on the economic damage to environments, the spatial extent of damage from local chemical use, the decision-making processes of business when dealing with environmental externalities. More multidisciplinary research is needed.

7 Summary analysis and lessons learnt

This paper has reviewed the economic analysis on the benefits of action (i.e. what has action on harmful chemicals achieved?) and the costs of inaction (i.e. what are the implications of doing no more?) on the management of harmful chemicals. The methods applied to generate these data are also assessed. Recommendations for future priorities are made. The Lancet commission on pollution and health:

"Pollution is very costly, it is responsible for productivity losses, health care costs and costs resulting from damages to ecosystems. But despite the great magnitude of these costs, they are largely invisible and often are not recognised as caused by pollution. The productivity losses of pollution-related diseases are buried in labour statistics. The health-related costs of pollution are hidden in hospital budgets. The result is that the full costs of pollution are not appreciated, [and] are often not counted"

(Landrigan et al. 2017).

7.1 Benefits of action

Whilst the precise course of action has differed across the world, extensive regulatory action taken to date has most likely avoided substantial damage to human health and the environment. Global treaties have ensured significant benefits have been secured over the mid to long term. Taking such action is not inconsistent with periods of population and economic growth. But there remains a lack of empirically based *ex-post* evidence. There is a need for more retrospective economic assessment, improved assessment of causal relationships, of unintended consequences and interaction between multiple exposures as well as effects of multiple regulations that may be acting on the same end point (Dudley 2017).

7.2 Costs of inaction

At a global level many health and environmental outcomes – such as incidence rates for several cancers - appear to be getting worse. Whilst there are several causal factors there is mounting economic analysis that ongoing exposure to harmful chemicals places substantial burdens on healthcare systems. That it can undermine the productivity and capability of the workforce and that some of this damage occurs before birth, in childhood, with effects persisting throughout life. The analysis suggests these costs occurring under the current policy framework are significant amount to several percent of global GDP. There is improving analysis of the economic damage to the environment, the spatial extent of damage as well as the nature and distribution of these costs.

7.3 Methods and research priorities

Robust economic analysis is technically challenging and requires several analytical inputs which are associated with uncertainties and debate (see Bolt 2017; Bond and Dietrich 2017). There are data gaps and methodological challenges to address (see Amec Foster Wheeler, 2017a for judgments on the data required for economic assessment in the context of chemical risks).

Existing techniques have limitations and currently do not fully capture the costs incurred in reduction in quality of life, pain and suffering. Cost of illness assessment requires accurate information on medical costs, but accurate data on the length of suffering, absence from work and hospital admission days are often missing, particularly in low and middle-income countries. Estimates are sensitive to technology used, its efficiency and efficacy that can vary between and within countries, along with systems of healthcare. Estimating the economic value of lost productivity requires assumptions on labour force participation, future productivity growth and wages as well as the marginal relationship between IQ and earnings. Effects on those not in the labour force and wider effects on households and on welling (utility) are often not included. Further research is needed to distinguish and attribute disease end points to specific chemicals or groups thereof, from more general lifestyle or non-chemical environmental factors.

The economic costs of inaction (and the benefits of action) are likely to be understated for three reasons. First, whilst progress has been made, the economic analysis is drawn largely from a group of comparatively well-studied chemicals, several of them the subject of regulation. A larger group are known or suspected pollutants but the effects are not quantified/attributed a monetary value. A larger group still have not been studied. Second, for even the well-studied group of chemicals, current economic approaches do not currently permit a quantification of all known economic effects. Third, very little quantified/monetary analysis exists of effects to the environment (ecosystems, biodiversity, plant and animal life, for example). The economic costs of inaction in these areas are not zero.

Available analysis on the BoA and CoI is overly biased toward a small number of high-income countries. It lacks national, subnational and social disaggregation. A disproportionate health burden may be falling on low and middle income countries from environmental exposure to chemicals, alongside ongoing lower level exposure – even to well-studied and regulated chemicals globally. There is pressing need for new research on a wider range of chemicals/groups, on a wider range of end points and exposure routes. Better models are needed to establish linkages between cause and effect with greater certainty and to incorporate effects from multiple exposures. This need is greatest in low and middle-income countries generally and for time series biomarker and biomonitoring data in these countries specifically.

The available analysis cannot easily be compared, reflecting temporal and methodological differences. Consistent methods, consensus on unit values and new empirical data on costs are required, building on recent research from the European Chemicals Agency (ECHA) and the OECD amongst others[37].

Recognising initiatives such as The Economics of Ecosystems and Biodiversity (TEEB) in laying foundations and furthering methods, there is a lack of data to quantify and assign monetary values to the impacts of chemical releases on ecosystems/natural capital and biodiversity[38].

The prominence of chemical pollution both with policy makers and the general public should be greater. The available analysis indicates a global problem. A thematic study into the economic and social effects

[37] See for example: https://echa.europa.eu/support/socio-economic-analysis-in-reach/willingness-to-pay-to-avoid-certain-health-impacts and http://www.oecd.org/env/ehs/risk-management/socio-economicanalysissea.htm and http://www.oecd.org/chemicalsafety/risk-management/sacame.htm

[38] http://www.teebweb.org/

of harmful chemical use, akin to the Stern Review on the Economics of Climate Change (Stern 2007), would usefully serve this purpose.

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