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Review

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Pollution and health: a progress update

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The *Lancet* Commission on pollution and health reported that pollution was responsible for 9 million premature deaths in 2015, making it the world's largest environmental risk factor for disease and premature death. We have now updated this estimate using data from the Global Burden of Diseases, Injuriaes, and Risk Factors Study 2019. We find that pollution remains responsible for approximately 9 million deaths per year, corresponding to one in six deaths worldwide. Reductions have occurred in the number of deaths attributable to the types of pollution associated with extreme poverty. However, these reductions in deaths from household air pollution and water pollution are offset by increased deaths attributable to ambient air pollution and toxic chemical pollution (ie, lead). Deaths from these modern pollution risk factors, which are the unintended consequence of industrialisation and urbanisation, have risen by 7% since 2015 and by over 66% since 2000. Despite ongoing efforts by UN agencies, committed groups, committed individuals, and some national governments (mostly in high-income countries), little real progress against pollution can be identified overall, particularly in the low-income and middle-income countries, where pollution is most severe. Urgent attention is needed to control pollution and prevent pollution-related disease, with an emphasis on air pollution and lead poisoning, and a stronger focus on hazardous chemical pollution. Pollution, climate change, and biodiversity loss are closely linked. Successful control of these conjoined threats requires a globally supported, formal science–policy interface to inform intervention, influence research, and guide funding. Pollution has typically been viewed as a local issue to be addressed through subnational and national regulation or, occasionally, using regional policy in higher-income countries. Now, however, it is increasingly clear that pollution is a planetary threat, and that its drivers, its dispersion, and its effects on health transcend local boundaries and demand a global response. Global action on all major modern pollutants is needed. Global efforts can synergise with other global environmental policy programmes, especially as a large-scale, rapid transition away from all fossil fuels to clean, renewable energy is an effective strategy for preventing pollution while also slowing down climate change, and thus achieves a double benefit for planetary health.

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Commission findings on pollution and health

Pollution— ie, unwanted waste of human origin released to air, land, water, and the ocean without regard for cost or consequence—is an existential threat to human health and planetary health, and jeopardises the sustainability of modern societies. Pollution includes contamination of air by fine particulate matter ($PM_{2·5}$); ozone; oxides of sulphur and nitrogen; freshwater pollution; contamination of the ocean by mercury, nitrogen, phosphorus, plastic, and petroleum waste; and poisoning of the land by lead, mercury, pesticides, industrial chemicals, electronic waste, and radioactive waste.

The 2017 *Lancet* Commission on pollution and health, which used data from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2015, found that pollution was responsible for an estimated 9 million deaths (16% of all deaths globally) and for economic losses totalling US$ 4·6 trillion (6·2% of global economic output) in 2015.[1] The Commission noted pollution's deep inequity: 92% of pollution-related deaths, and the greatest burden of pollution's economic losses, occur in low-income and middle-income countries (LMICs).

This report presents an updated estimate of the effects of pollution on health, made on the basis of the GBD 2019 data, and also makes an assessment of trends since 2000. These data show that the situation has not improved, and that pollution remains a major global threat to health and prosperity, particularly in LMICs. Since 2000, the steady decline in the number of deaths from the ancient scourges of household air pollution,

Key messages

- Over the past two decades, deaths caused by the modern forms of pollution (eg, ambient air pollution and toxic chemical pollution) have increased by 66%, driven by industrialisation, uncontrolled urbanisation, population growth, fossil fuel combustion, and an absence of adequate national or international chemical policy.
- Despite declines in deaths from household air and water pollution, pollution still causes more than 9 million deaths each year globally. This number has not changed since 2015.
- More than 90% of pollution-related deaths occur in low-income and middle-income countries.
- Key areas in which focus is needed include air pollution, lead poisoning, and chemical pollution. Air pollution causes over 6·5 million deaths each year globally, and this number is increasing. Lead and other chemicals are responsible for 1·8 million deaths each year globally, which is probably an undercounted figure.
- Most countries have done little to deal with this enormous public health problem. Although high-income countries have controlled their worst forms of pollution and linked pollution control to climate change mitigation, only a few low-income and middle-income countries have been able to make pollution a priority, devoted resources to pollution control, or made progress. Likewise, pollution control receives little attention in either official development assistance or global philanthropy.
- The triad of pollution, climate change, and biodiversity loss are the key global environmental issues of our time. These issues are intricately linked and solutions to each will benefit the others.
- We cannot continue to ignore pollution. We are going backwards.

	Female	Male	Total
Total air pollution*	2·92 (2·53–3·33)	3·75 (3·31–4·25)	6·67 (5·90–7·49)
Household air†	1·13 (0·80–1·50)	1·18 (0·79–1·66)	2·31 (1·63–3·12)
Ambient particulate‡§	1·70 (1·38–2·01)	2·44 (2·02–2·83)	4·14 (3·45–4·8)
Ambient ozone‡	0·16 (0·07–0·25)	0·21 (0·09–0·33)	0·37 (0·17–0·56)
Total water pollution*	0·73 (0·40–1·26)	0·63 (0·46–0·95)	1·36 (0·96–1·96)
Unsafe sanitation†	0·40 (0·23–0·68)	0·36 (0·26–0·54)	0·76 (0·54–1·09)
Unsafe source†	0·66 (0·35–1·15)	0·57 (0·39–0·88)	1·23 (0·82–1·79)
Total occupational pollution*	0·22 (0·17–0·28)	0·65 (0·54–0·79)	0·87 (0·74–1·02)
Carcinogens‡	0·07 (0·05–0·09)	0·28 (0·22–0·35)	0·35 (0·28–0·42)
Particulates‡¶	0·15 (0·10–0·21)	0·37 (0·27–0·47)	0·52 (0·42–0·64)
Lead pollution*‡	0·35 (0·19–0·53)	0·56 (0·36–0·77)	0·90 (0·55–1·29)
Total modern pollution*	2·28 (1·86–2·67)	3·55 (3·08–4·04)	5·84 (5·03–6·61)
Total traditional pollution*	1·85 (1·39–2·42)	1·81 (1·36–2·38)	3·66 (2·82–4·63)
Total pollution*	3·92 (3·39–4·47)	5·09 (4·57–5·68)	9·01 (8·12–10·0)

Data are N in millions (95% CI). *Custom aggregate from Institute for Health Metrics and Evaluation corrected for overlap. The totals for air, water, modern, traditional, and all pollution are less than the arithmetic sum of the individual risk factors within each of these categories because their contributions overlap (eg, household air and ambient air pollution each can contribute to the same diseases). †Traditional pollution risk factor. ‡Modern pollution risk factors. §Ambient particulate matter is $PM_{2.5}$. ¶Occupational exposure to respirable, thoracic, or inhalable particulate matter.

Table: **Global estimated pollution-attributable deaths (millions) by type of pollution and sex, 2019**

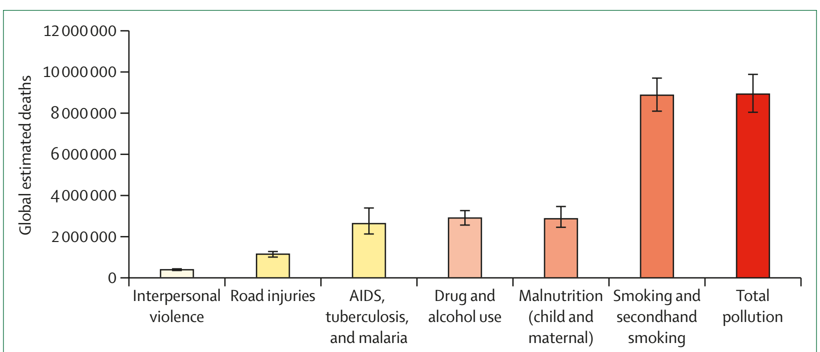

Figure 1: **Global estimated deaths by major risk factor or cause**
Data from Institute for Health Metrics and Evaluation and Global Burden of Diseases, Injuries, and Risk Factors Study 2019.[6] Error bars are 95% CI.

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unsafe drinking water, and inadequate sanitation are offset by increasing deaths attributable to the more modern forms of pollution. These modern forms of pollution—eg, ambient air pollution, lead pollution, and chemical pollution—require major increases in mitigation and prevention.

Death and disease due to pollution in 2019

The analysis of disease and premature death due to pollution that we present uses GBD methodology that was developed in the 1990s by WHO, which was expanded by the Institute for Health Metrics and Evaluation (IHME).[2] Similar to earlier iterations of the GBD study, the 2019 study included new input data and several methodological updates.[3] Given the large number of chemical pollutants and their ubiquity in the modern environment, the disease burden attributable to chemical pollution is likely to be substantially greater than current estimates.[4]

Pollution-related death

In 2019, pollution was responsible for approximately 9·0 million premature deaths. Air pollution (both household and ambient air pollution) remains responsible for the greatest number of deaths, causing 6·7 million deaths in 2019. Water pollution was responsible for 1·4 million premature deaths. Lead was responsible 900 000 premature deaths. Toxic occupational hazards, excluding workplace fatalities due to safety hazards, were responsible for 870 000 deaths (table). The total effects of pollution on health would undoubtedly be larger if more comprehensive health data could be generated, especially if all pathways for chemicals in the environment were identified and analysed.[5]

The GBD 2019 data show that the effect of pollution on disease and disability varies by sex. Men are more likely to die from exposure to ambient air pollution, lead pollution, and occupational pollutants than women. Women and children are more likely to die from exposure to water pollution than men.

A comparison of the effects of pollution on morbidity and mortality with those of other risk factors on morbidity and mortality shows that pollution continues to be one of the largest risk factors for disease and premature death globally. The impact of pollution on health remains much greater than that of war, terrorism, malaria, HIV, tuberculosis, drugs, and alcohol, and the number of deaths caused by pollution are on par with those caused by smoking (figure 1).[6]

Trends in pollution and pollution-related death and disease: 2000–19 and 2015–19

The decline in deaths from traditional pollution (ie, household air pollution from solid fuels and unsafe water, sanitation, and hand washing) is most evident in Africa, where improvements in water supply, sanitation, antibiotics, treatments, and cleaner fuels have made measurable inroads in mortality statistics (figure 2).[6]

Deaths from the modern forms of pollution (ie, ambient particulate matter air pollution, ambient ozone pollution, lead exposure, occupational carcinogens, occupational particulate matter, gases, fumes, and environmental chemical pollution) have increased substantially over the past 20 years on a global scale. Ambient air pollution was responsible for 4·5 million deaths in 2019. This proportion is an increase from 2015, when ambient air pollution was responsible for 4·2 million deaths, and 2000, when it was responsible for 2·9 million deaths. These increases were due to increases in ambient air pollution and in the incidence of non-communicable diseases (NCDs) linked to air pollution.

Increases in deaths from the more modern forms of pollution are particularly evident in south Asia, east Asia, and southeast Asia (figure 3).[6] Rising ambient air pollution, rising chemical pollution, ageing populations, and increased numbers of people exposed to pollution are the factors responsible for these increased numbers of deaths.[3]

In Africa, household air pollution and water pollution are still the predominant causes of pollution-related disease and death, but the amount of ambient air pollution and the number of deaths from air-pollution-related NCDs have begun to increase as African countries develop economically, industrialise, build infrastructure, and become increasingly urbanised.[7,8] Increases are most marked in the most rapidly emerging African economies. Data show that there has been improvement in the morality rate (number of deaths per 100 000 population) attributable to $PM_{2\cdot5}$ in some cities in Africa.[9]

Pollution issues of growing concern

The persistence of lead pollution

With the decision made by the Government of Algeria, in 2021, to remove lead from its gasoline supply, lead has now been removed from automotive fuel in every country in the world. This decision represents a major triumph for public health and has resulted in a worldwide reduction of lead blood concentrations in children and a reduction in the prevalence of lead poisoning. However, despite these advances, lead remains a major threat to health.

The GBD 2019 estimated that lead exposure is annually responsible for 0·9 million deaths (95% CI 0·55–1·29) worldwide but this estimate is probably a substantial undercount, because new data from long-term studies of American adults suggest that the cardiovascular and renal toxicity of lead could extend down to much lower blood lead concentrations than previously recognised and that there might be no threshold for these effects.[10–12]

Furthermore, analyses have documented that elevated blood lead concentrations and lead poisoning in children, especially in LMICs, are much more widely prevalent than previously recognised (figure 4).[13,14] More than 800 million children are estimated to have blood lead concentrations that exceed 5·0 μg/dL, which was, until 2021, the concentration for intervention established by the US Centers for Disease Control and Prevention. This concentration has now been reduced to 3·5 μg/dL.[14] The implications of this finding for children's intellectual impairment are staggering. Children with blood lead concentrations higher than, or equal to, 5·0 μg/dL could score 3–5 points lower on intelligence tests than children with blood lead concentrations lower than 5·0 μg/dL. Furthermore, higher blood lead concentrations are associated with serious losses of cognitive function.[15] Lead-related IQ losses are associated with increased rates of school failure, behavioural disorders, diminished economic productivity, and global economic losses of almost $1 trillion annually. In Africa, the economic losses from lead-related IQ loss are equivalent to about 4% of gross domestic product (GDP) and in Asia, these losses are equivalent to 2% of GDP.[14]

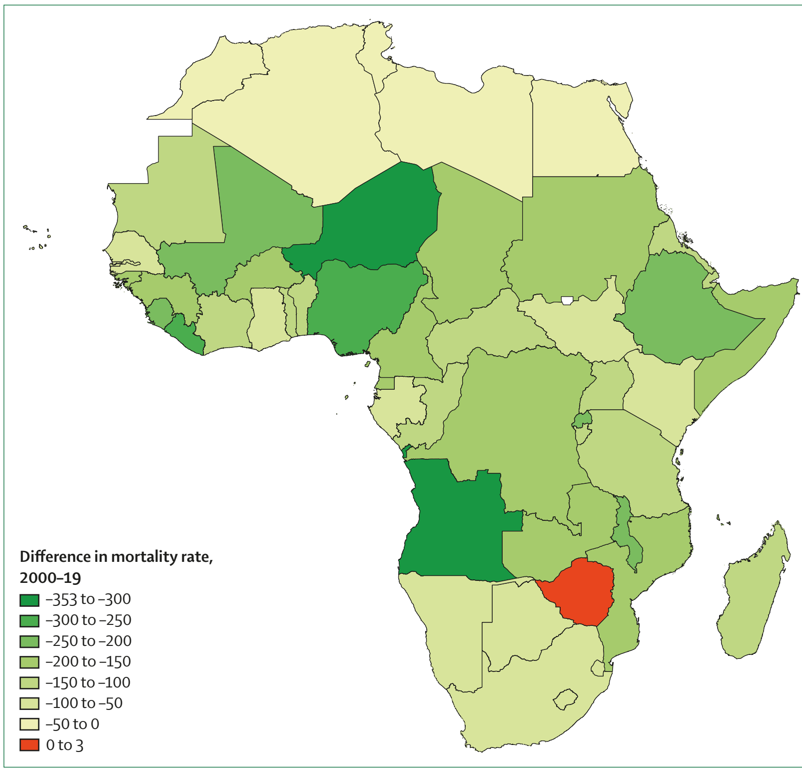

Figure 2: **Downward trend in mortality rate from traditional pollution in Africa, 2000–19**
Mortality rate is deaths per 100 000 population. Data from Institute for Health Metrics and Evaluation and Global Burden of Diseases, Injuries, and Risk Factors Study 2019.[6]

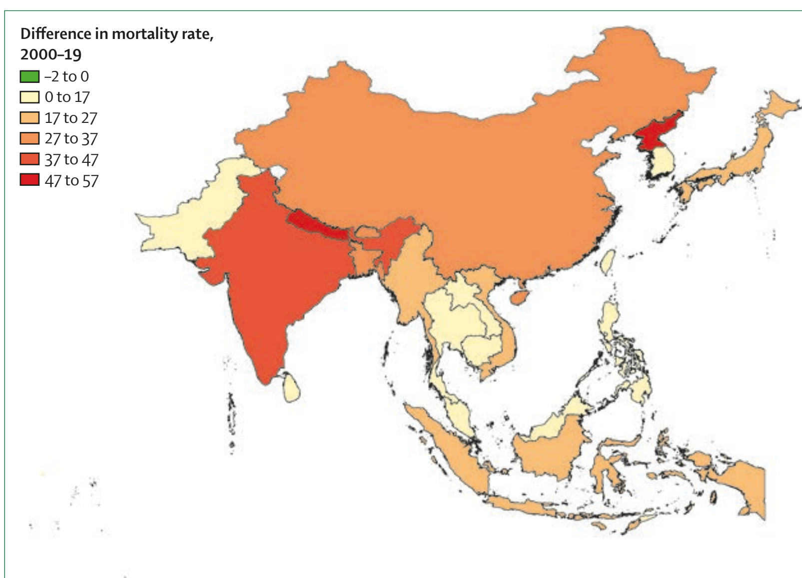

Figure 3: **Upward trend in mortality from traditional pollution in south Asia and southeast Asia, 2000–19**
Mortality rate is deaths per 100 000 population. Data from Institute for Health Metrics and Evaluation and Global Burden of Diseases, Injuries, and Risk Factors Study 2019.[6]

Today, the principal sources of lead exposure include unsound recycling of lead–acid batteries and e-waste without pollution controls;[16–18] spices that are contaminated

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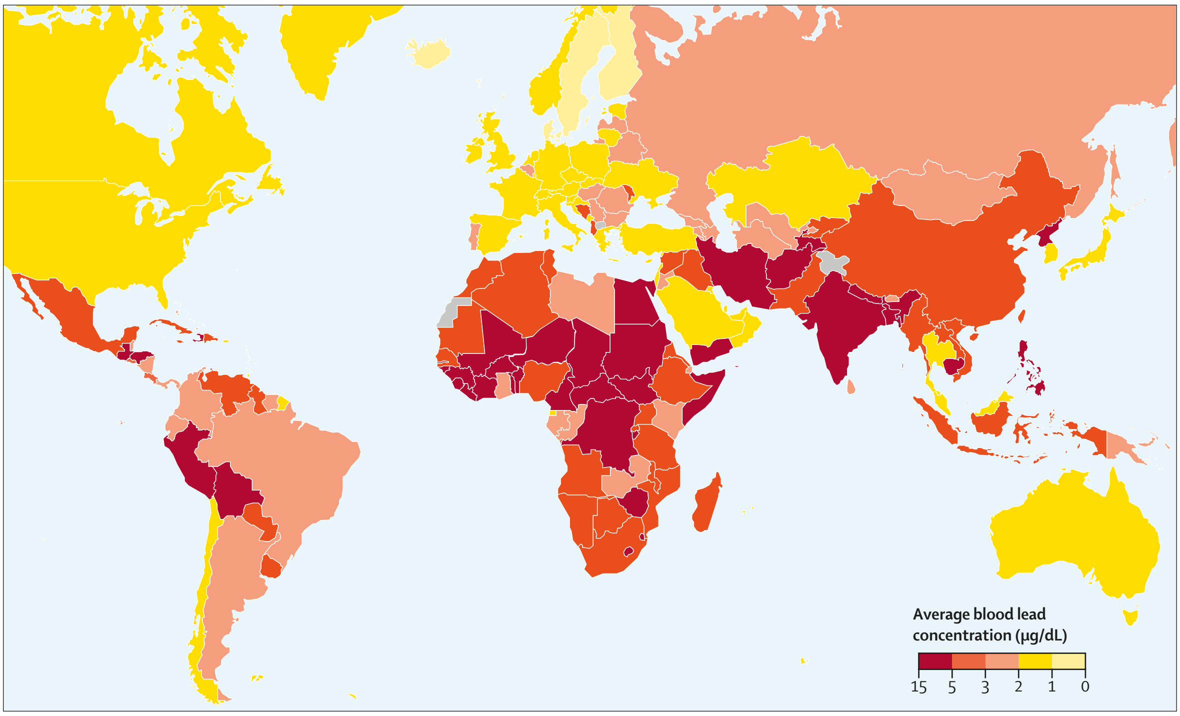

Figure 4: **Global distribution of childhood lead exposures in 2019**
Childhood lead exposures represented by average blood lead concentration (µg/dL). This figure is reproduced from a previous report[14] by permission of UNICEF and Pure Earth.

with lead;[19,20] pottery glazed with lead salts, which leach out into acidic foods;[21,22] and lead in paint and other consumer products.[23] The full extent of population exposure to each of these sources varies by country and is often unknown.

The intersection of climate change and air pollution

Air pollution is entwined with climate change because the emissions driving both development problems come largely from the same sources (eg, fossil fuel or biofuel burning). Burning fuels results in fine and ultrafine particulates (eg, $PM_{2·5}$ and others), long-lived greenhouse gases, and short-lived climate pollutants (SLCPs). SLCPs are simultaneously air pollutants and climate warmers. The primary SLCPs are methane, black carbon (ie, soot), and hydrofluorocarbons.[24] Methane emissions emitted up to and including 2019 account for approximately a third of the warming effect of all well mixed greenhouse gas emissions and for 45% of the net warming effect of all anthropogenic activities.[25,26] Methane emission is one of the main precursors to ground level ozone, which is a major source of premature death. Black carbon is a component of $PM_{2·5}$ and is also a SLCP with a global warming potential that is 460–1500 times higher than that of carbon dioxide. Black carbon emissions emitted up to and including 2019 account for approximately 8% of the net warming effect of all anthropogenic activities.[24] Solid fuels that are used for domestic purposes contribute to 58% of global black carbon emissions.[27] Some air pollutants (eg, sulphates, nitrates, and some types of $PM_{2·5}$) lead to climate cooling. Policies that do not simultaneously optimise climate change mitigation and air quality run the risk of causing unanticipated trade-offs or so-called win–lose outcomes, but policies that do can result in synergies that benefit both climate and health.[28,29,30] SLCPs have a relatively short residence time in the atmosphere (ie, less than approximately 15 years); for this reason, SLCP reductions are the strongest lever available to slow the rate of warming and the mounting toll of climate change events in the next few decades.

The silent threat of chemical pollution

Chemicals have become widely disseminated in the global environment. Global chemical manufacturing is increasing at a rate of about 3·5% per year and is on track to double by 2030.[4] Approximately two-thirds of current chemical production is in LMICs.

Undercounting of the disease burden attributable to chemical pollution is probably substantial, because only a small fraction of the many thousands of manufactured chemicals in commerce have been adequately tested for safety or toxicity, and the disease burdens attributable to these chemicals cannot be quantified. Three particularly worrisome, and inadequately charted, consequences of chemical pollution are developmental neurotoxicity, reproductive toxicity, and immunotoxicity.

Developmental neurotoxicity of chemicals

Over 200 chemicals, including lead, methylmercury, polychlorinated biphenyls, arsenic, organochlorine and organophosphate pesticides, organic solvents, and brominated flame retardants are neurotoxic to humans,[31] and many of these chemicals are widespread in the modern environment.[4] Children are particularly susceptible to their effects: even low-dose exposures to neurotoxic chemicals during key periods of developmental vulnerability in fetal and postnatal life have more serious effects on health than high-dose exposures to the same chemicals in adults.[32,33]

Reproductive toxicity of chemicals

Evidence is strong and growing that exposure to particular manufactured chemicals, even at low doses, can have adverse effects on fertility and pregnancy. Pesticides, industrial chemicals (eg, halogenated flame-retardants, plasticisers, and dioxins), environmental chemicals of pharmaceutical origin, and toxic metals have been linked to a range of reproductive problems.[4,34] Prenatal and early postnatal exposure to chemicals also appear to be linked to an increased incidence of reproductive diseases later in life, including endometriosis, breast cancer, cervical cancer, uterine cancer, and testicular cancer.[4]

Immunotoxicity of chemicals and implications for communicable disease control

Some pollutants are toxic to the immune system. For example, perfluoroalkyl acids have been associated with reduced antibody responses to vaccines,[35] increased risk in children for hospitalisation with infectious disease,[36] and increased severity of COVID-19 infections.[37] Exposure to traffic-related air pollution[38] has been associated with increased mortality from COVID-19 and exposure to cadmium[39] has been associated with increased mortality from influenza. Many other chemical exposures have been shown to be toxic to the immune system in laboratory studies;[40] although research on the clinical consequences of exposure is still scarce.

Transboundary pollution

Although most pollution remains near pollution sources in countries of origin, a growing body of evidence shows that transboundary pollutants can travel long distances in wind, in water, through the food chain, and in consumer products. Global winds transport air pollution from east Asia to North America, from North America to Europe, and from Europe to the Arctic and central Asia.[41] A substantial portion of air pollution exposure in Europe originates from non-European sources.[42] Industrial activity in China has increased airborne pollutants in places as near as Japan, South Korea, and Taiwan, and as far away as California, USA.[43,44]

The drivers of pollution also extend across less tangible boundaries. Wealthier countries displace their pollution footprints overseas, whereas lower-income countries experience increasing pollution domestically.[45] China has both problems. As China successfully reduced $PM_{2·5}$ emissions from household and domestic factories, emissions generated by export production rose, with more than 60% of this increase associated with the manufacture of goods destined for use in Organisation for Economic Co-operation and Development (OECD) countries.[46]

It is not just air pollution that moves globally. The contamination of cereals, seafood, chocolate, and vegetables produced in LMICs for export increasingly threatens global food safety. This contamination is a consequence of soil and water in LMICs that are polluted with lead, arsenic, cadmium, mercury, and pesticides.[47–49] Toxic metals found in infant formulas and baby foods are of particular concern.[50–53] There have been few studies on this issue in LMICs, although turmeric contaminated by lead has been identified in several locations in Bangladesh, a problem that is likely to be widespread.[19]

Economic impacts of pollution

The economic losses associated with deaths due to pollution can be valued by the output lost when a person dies prematurely (ie, the human capital approach), or by using the value per statistical life (ie, what people would pay for small risk reductions that sum up to one statistical life), which we refer to as welfare losses. The 2017 *Lancet* Commission on pollution and health, which used the value per statistical life approach, found that welfare economic losses associated with 2015 pollution were equal to 6·2% of world GDP, and 82% of these economic losses were attributed to ambient air pollution and household air pollution. A World Bank study on health costs of $PM_{2·5}$ air pollution using GBD 2019 data showed that, in 2019, the global economic welfare losses attributable to household air pollution and ambient $PM_{2·5}$ air pollution amounted to 6·1% of global economic output.[54] The economic effects of air pollution are especially severe in regions of east Asia and the Pacific, where losses are equivalent to 9·3% of GDP, and south Asia, where losses are equivalent to 10·3% of GDP.[54]

For this Review, instead of repeating global calculations, we used the human capital approach to evaluate the cost of modern pollution on a subset of countries' prospects for economic growth and societal development.[55] Specifically, we estimated the present value of future output lost when a person dies prematurely due to pollution. Six countries or regions were chosen: India and China, which are the two most populous countries globally; Nigeria and Ethiopia, which are the two most populous countries in Africa; the USA, which has the world's largest economy; and EU15, which is a large economic entity with common pollution standards across member states (figure 5).[6,56,57]

Traditional pollution

In 2000, output losses due to traditional pollution were 6·4% of GDP in Ethiopia, 5·2% of GDP in Nigeria, and

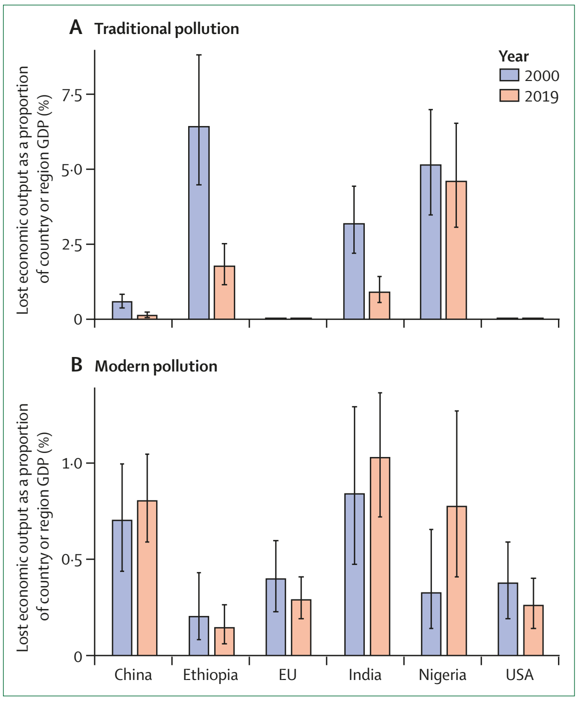

***Figure 5*: Lost economic output as a proportion of country GDP due to deaths from modern and traditional pollution in 2000 and 2019**

(A) Traditional pollution includes deaths from household air pollution from solid fuels and unsafe water, sanitation, and hand washing.[6,56,57] (B) Modern pollution includes deaths from ambient ozone pollution, ambient particulate matter pollution, lead exposure, occupational carcinogens, occupational particulate matter, gases, and fumes.[6,56,57] GDP=gross domestic product.

3·2% of GDP in India. These output losses were huge burdens on the economies of these countries. By 2019, death rates due to traditional pollution were a third of the death rate in 2000 in Ethiopia and Nigeria, and less than half of the death rate in 2000 in India. Consequently, pollution-related economic losses as a proportion of GDP fell substantially. Nonetheless, economic losses due to traditional pollution are still approximately 1·0% of GDP in India and 2% of GDP in Ethiopia. In Nigeria, economic losses from traditional pollution are more than 4·6% of GDP, due to the increase in the value of workers' output in Nigeria over the past 20 years.

See Online for appendix

Modern pollution

Economic losses due to modern forms of pollution have increased as a proportion of GDP between 2000 and 2019 in India, China, and Nigeria, and are now conservatively estimated to amount to approximately 1·0% of GDP in each of these countries. The full economic losses, if the full health impacts of pollution were to be counted and the effects of pollution on informal sectors and environmental damage were to be fully detailed, are likely to be greater. By contrast, economic losses due to modern forms of pollution have fallen as a proportion of GDP in the USA and in EU15 countries. The reduction of economic losses in these countries reflects pollution control, the outsourcing of polluting industries, and reductions in death rates.

Progress in addressing pollution and pollution related disease

The *Lancet* Commission on pollution and health made science-based recommendations in 2017 for action against pollution on the basis of data from the GBD 2015.[1] Since 2017, there has been strikingly little effort in most countries to act on these recommendations or to prioritise action against pollution. For example, although GBD 2019 calculates that lead currently contributes to over 900 000 premature deaths each year,[6] international attention and funding on chemical pollution is more focused on emerging issues such as perfluorinated and polyfluorinated alkyl substances and endocrine disruptors, for which the global burden of disease is less clear than on lead. Likewise, ministries of health continue to prioritise infectious diseases and disease treatment, leaving pollution prevention to the ministries of environment, which usually have less power and less funding than ministries of health. The powerful ministries of finance, urban development, and energy, which make the key investment decisions that shape options in energy choices and development pathways, are seldom involved in pollution control. Despite strong and growing evidence for pollution's contribution to NCD morbidity and mortality, international and national NCD control programmes focus almost exclusively on behavioural and metabolic risk factors such as tobacco use, exercise, and obesity, while ignoring pollution.[58]

As health improvements typically occur several years after changes in policy, major reductions in the burden of disease attributable to pollution could not reasonably be expected to be visible in this 4-year review of IHME data. However, our review of pollution policies in countries around the world finds little substantive progress in the development of pollution-control policies, even in the most severely affected countries, which are mostly LMICs. High-income countries with active programmes to control air pollution and chemical pollution continue to show advances, but only a handful of LMICs show measurable advances (appendix pp 1–4). The absence of quantitative data on pollution rates and population exposures, particularly for chemical pollution, means that assessment of progress for most issues relies largely on specialist knowledge and opinion.

We summarise responses to the *Lancet* Commission's recommendations in the following paragraphs. In general, responses have been weak and have been overwhelmed within national development agendas by a focus on climate change and COVID-19.

Prioritise pollution prevention and health protection nationally and internationally

International attention to pollution reduction has been growing, albeit slowly and unevenly. Most notably, the

UN Environment Programme has identified pollution as one of three key pillars of its 2022–25 strategy, alongside climate change and biodiversity loss.[59] WHO has substantially tightened its health-based global air quality guidelines, lowering the guideline value for $PM_{2·5}$ from 10 μg/m³ to 5 μg/m³.[60] WHO has also issued new guidance on medical management of lead exposure, and has linked air pollution reduction to climate change mitigation and NCDs.[61]

In national programmes, China has incorporated pollution-control targets into its most recent 5-year plan, and has begun to reduce air pollution in several large urban areas.[62,63] Mexico City, Bangkok, and other major cities have had some success against ambient air pollution.[64] India has made efforts against household air pollution, most notably through the Pradhan Mantri Ujjwala Yojana programme, but in 2019 still had the world's largest estimated number of air pollution-related deaths.[55] The EU has a domestic Zero Pollution Action Plan as part of the European Green Deal, which also includes a small international component.[65] These initiatives are all important steps, but much more is needed.

Mobilise, increase, and focus funding and international technical support for pollution control

The international funding response for pollution prevention has been meagre. Only a small number of bilateral and multilateral agencies and organisations are promoting the health and pollution agenda, and even those efforts receive only little support.

An analysis of available OECD figures for 2016 on official development assistance (ODA) concluded that donor countries have not responded to the global crisis of pollution-related disease and death through expanded investment in pollution control.[66] A 2019 study of ODA from bilateral and UN agencies allocated to reducing modern pollution found that support fluctuated from year to year and that there was no overall upward trend.[66] ODA contributions to international conventions and frameworks concerning pollutants and chemicals amounted to $860 million in 2016–18, which is inadequate for the size and scope of the problem. Private philanthropic funding for pollution control also remains scarce.[67,68]

Establish systems to monitor and control pollution

Monitor air pollution and its effects on health

China and India, countries with massive pollution challenges, have been making substantial investments in monitoring and planning to support pollution reduction efforts. Extensive efforts in China to control the burning of solid fuels under National Air Quality Action Plans have resulted in marked decreases in the amount of pollution. In the Beijing region, mean ambient $PM_{2·5}$ concentrations have dropped by nearly 40%.[69] Nationally, population-weighted $PM_{2·5}$ exposures fell to 48 μg/m³ in 2019, from 63 μg/m³ in 2013.[70] India has developed instruments and regulatory powers to mitigate pollution sources but there is no centralised system to drive pollution control efforts and achieve substantial improvements.[71] In 93% of India, the amount of pollution remains well above WHO guidelines.[72] International organisations have supported various databases to monitor air quality.

In Europe and North America, most urban areas have one or more reference-grade ambient air quality monitoring stations, which represents about one monitor per 100 000–600 000 residents. By contrast, across sub-Saharan Africa, there is just one ground-level monitor per 15·9 million people.[73,74] Only seven of 54 African countries currently have reliable real-time air quality monitoring. Although improved satellite imaging and analysis are helping to fill gaps,[75] satellite estimates of surface $PM_{2·5}$ concentration could have errors in the range of 22–85% if they are not calibrated by ground-level monitoring data.[76] South Africa has continuous air quality monitoring systems. Other countries, including Ghana, Nigeria, and Senegal, have carried out monitoring programmes at intervals, although funding for maintenance and quality control is sporadic.

Monitor lead pollution

Monitoring lead exposures requires population-wide blood lead testing, especially in pregnant women and in children, because of the neurological effects of lead on brain development early in life. Outside of high-income countries these monitoring programmes are almost non-existent. Pilot studies in Mexico have catalysed a national programme to identify and control lead exposure in children and pregnant women.[77] UNICEF has initiated a baseline programme in Georgia,[78] and the Philippines is planning to incorporate lead testing in its next country survey. China has also made initial efforts to determine baseline lead exposures.[79]

Most LMICs do not have population-wide blood lead or environmental lead monitoring systems in place.[80] A multistakeholder approach to addressing lead exposure—ie, Protecting Every Child's Potential—has been initiated with UNICEF and others.[81]

Monitor water, sanitation, and hygiene

Despite continued efforts over many decades and continuing improvements, inadequate water, sanitation, and hygiene (WASH) remains a major global risk factor for disease and premature death and has serious health and socioeconomic consequences, particularly for women and girls living in LMICs.[82]

Considerable expansion of access to clean water and sanitation services has been achieved in the past 50 years, but a 2018 review of progress towards the achievement of the targets set under the Sustainable Development Goals (SDGs) concluded that it would be an enormous challenge to close existing gaps in coverage by 2030.[83] A fundamental problem is that rapidly growing populations in LMICs often outstrip efforts to provide clean water and sanitation, with the result that the number of people worldwide who do not have adequate access to these services remains high despite valiant efforts.[84] According to UN estimates, 2·2 billion people still do not have access to safe drinking water and 4·2 billion do not have access to safely managed sanitation services.[85]

Monitor chemical pollution

For most of the thousands of manufactured chemicals now in commerce there are no reliable data on developmental toxicity, reproductive toxicity, immunotoxicity, the effects of long-term low-level exposures, or the health risks of chemical mixtures.[86] Despite substantial progress in the international arena since the 1990s to establish multilateral agreements regulating some chemicals in waste, "the global goal of sound chemicals and waste management in ways that lead to minimized adverse effects on human health and the environment" has not been achieved.[87]

A process to establish a science–policy interface (SPI) for chemicals and wastes[88] has been launched at the UN Environment Assembly in 2022. Such a programme mirrors the Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. It will be important for WHO to be fully involved in launching the process, and the scope of this programme should preferably span all forms of pollution. The SPI would need to receive broad governmental and multilateral support (including funding), and should draw on existing knowledge and expertise from a wide range of stakeholders.

Build multisectoral partnerships for pollution control

Pollution is rarely highlighted in multilateral bank or UN Development Programme country planning strategies, and only a handful of countries have begun the process of integrating pollution responses into their development strategies, in the context of many other competing demands. A useful approach to helping governments prioritise pollution issues on the basis of their health impacts is the Health and Pollution Action Plan (HPAP) or similar processes. The HPAP is a prioritisation process designed to assist governments of LMICs to identify their most important pollution problems and to develop and implement solutions.[89] Although ambient air pollution might already be on the agenda, the HPAP process often brings up serious problems with toxic chemicals and metals. Currently about a dozen countries have done such processes, with support from donors and UN agencies (appendix p 23). The HPAP is led by a government agency and is structured to bring together agencies and parties who usually do not interact. Although the HPAP process ensures strong local ownership and prioritised programmes, it is challenging to find funding for the process itself and for HPAP programme implementation.

International policy efforts to combat pollution remain fragmented and uncoordinated. Air pollution is dealt with regionally, with the UN Economic Commission for Europe Convention on Long Range Transboundary Air Pollution providing the most comprehensive set of agreements and monitoring arrangements. Water pollution is dealt with at the level of river basins or through Regional Seas Conventions. The major health effort is the UN Water, Sanitation and Hygiene programme. Industrial pollution of water receives little international attention and 6 years after the adoption of Agenda 2030, which established suitable indicators for tracking chemical pollution of waterways, this information is still not being collected.

Control of chemical and hazardous waste pollution is especially fragmented. The Strategic Approach to International Chemicals Management is the only comprehensive process that targets this issue, and it is entirely voluntary and has a very small budget. The UN Environment Programme is currently the only UN agency to prioritise addressing all types of pollution. UNICEF has taken up air pollution and is just beginning to add lead to its country portfolios.

Integrate pollution mitigation into planning processes for NCDs

Pollution is a major risk factor for NCDs. In 2018, air pollution (household and ambient) was recognised by WHO as one of five major risk factors for NCDs, alongside unhealthy diets, smoking, harmful use of alcohol, and physical inactivity.[90] The NCD Alliance has advocated for pollution's inclusion on the list of major risk factors. So far, however, little action has occurred in terms of funding or coordination with pollution agencies in programmes in the field, and no targets or timetables have been set.

Research pollution and pollution control

There has been growing attention paid to pollution in the research community, with some funding successes. Funded through the EU, the European Human Exposome Network is the largest research group in the world studying the effect of environmental risk factors, including pollution, on human health. In the USA, the Superfund Research Program has made valuable contributions and has extended its reach globally through the Pacific Basin Consortium for Environment and Health. However, there is little comparable work in LMICs and more sharing of relevant research and results is needed.

For the **European Exposome Network** see https://www.humanexposome.eu/about/

Highlight pollution control in the SDGs

The SDGs were adopted by the UN General Assembly in 2015 as part of the Agenda 2030 action plan. The 17 goals are supported by 169 targets measured through 231 indicators. Although none of the goals is exclusively devoted to pollution or its effects on health, there are targets and indicators of relevance to pollution control scattered throughout the goals. These goals aim to provide globally agreed information on the drivers of pollution, the amount of pollution, and on institutional responses to pollution. However, the relevant targets are less concrete than for some other challenges and are therefore unlikely to attract adequate political attention and resources.

The agreed Target 3.9 indicators for ambient air pollution, household air pollution, unsafe sanitation, and unsafe water sources are derived from the sex-disaggregated GBD mortality data. However, the chosen indicator for chemical pollution is deficient because it relates to deaths from accidental poisonings, which is not an adequate proxy for morbidity from NCDs due to chronic chemical pollution. The indicator should rely on the various forms of chemical pollution tracked by the GBD study.

Tracking awareness of pollution and health

Continued tracking of plans, expenditures, and action on pollution by national and local governments is essential. However, it is also important to track public attention to issues of pollution and health because the public demand for more effective action against pollution by governments can be powerfully catalytic.

Two metrics that can be tracked over time as proxies for public awareness of pollution and health are: the inclusion of pollution prevention in development strategy frameworks; and media attention to topics relating to pollution and health.

Inclusion of modern pollution prevention in multilateral development institutions' country strategy frameworks

To assess the frequency of support for pollution control programmes in Country Partnership Frameworks and equivalent documents developed by the World Bank, regional development banks, and the UN Development Programme, a text analysis was performed across these reports for the years 1995–2020, covering a period when new efforts could be expected to begin emerging (appendix p 28). The results show that from 1995 to 2020, discussions of pollution and biodiversity remained relatively constant, whereas discussion of climate change increased. Further, between 2015 and 2020, the terms "household air pollution" and "water pollution" were mentioned more often than "ambient air pollution" or "chemical pollution", suggesting a greater focus on traditional pollution than modern pollution (figure 6).[91–95]

These findings mirror the results of a 2017 review conducted by the World Bank's Independent Evaluation Group.[96] This review found that only 28% of World Bank Group country strategies referenced pollution concerns. Most strategy documents (56%) did not mention pollution.

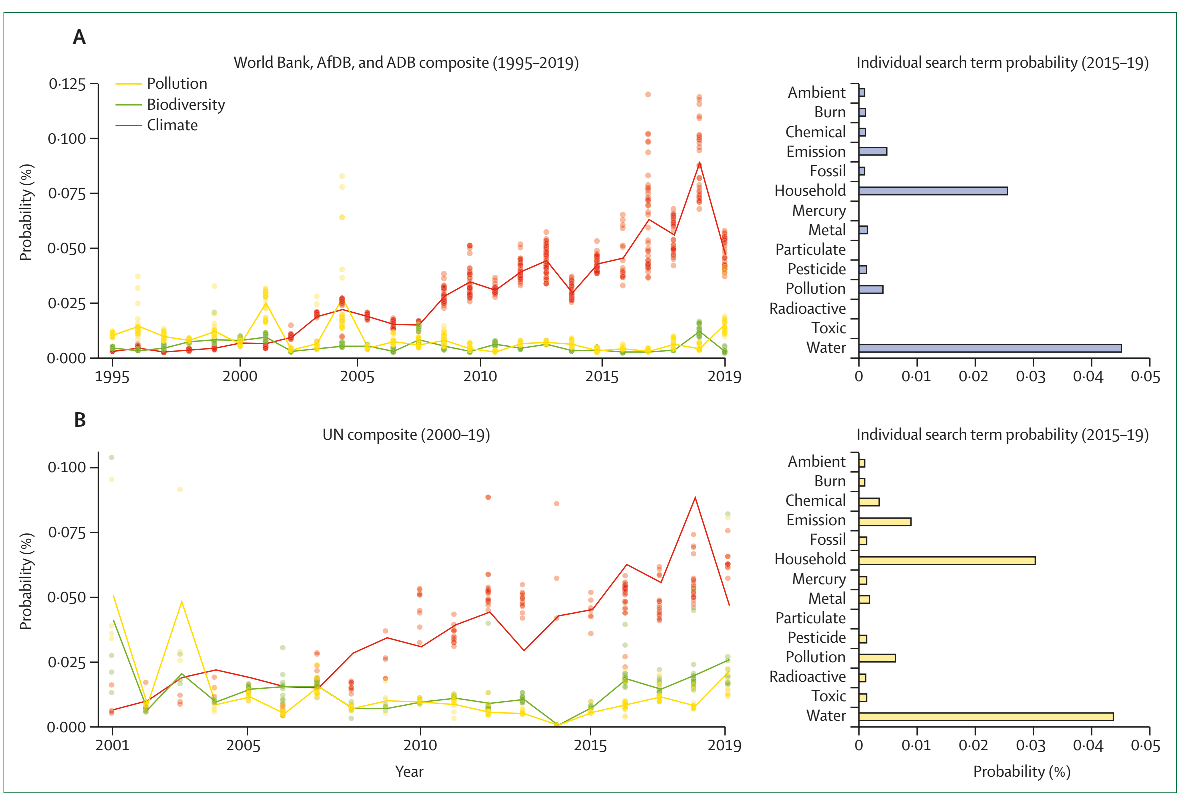

Figure 6: **Probability of subject matter coverage of pollution, biodiversity, and climate change (composite terms and key phrases) in country framework documents**

(A) Composite data are from the World Bank, the AfDB, and the ADB (1995–2019); data for individual search terms are from the World Bank (2015–19).[91–94] (B) Composite data are from UN (2000–19); data for individual search terms are from UN (2015–19).[95] AfDB=African Development Bank. ADB=Asian Development Bank.

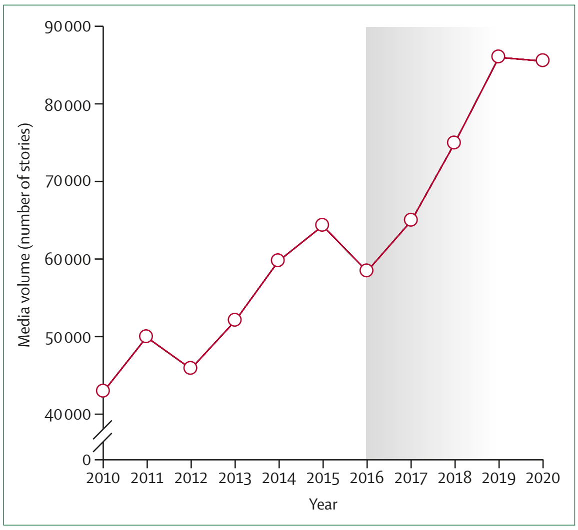

Figure 7: **Coverage of modern pollution topics in major media outlets in 2020**
Data obtained through a search of the Factiva database from Jan 1, 2010, to Dec 31, 2020.

Number of stories in major media covering pollution issues

We conducted an analysis focused on coverage of modern pollution in English language media since 2010 (appendix p 30). For traditional media (ie, in print, online, and broadcasted), a search of the Factiva database yielded 1794 677 articles dealing with topics on pollution. A breakdown of this search by year reveals a steadily rising trend in coverage (figure 7). The largest annual increases were seen in the years 2017–19, following publication of the report of the *Lancet* Commission on pollution and health in 2017. Clearly, public interest in pollution is strong and growing.

Conclusion and recommendations

Despite its substantial effects on health, societies, and economies, pollution prevention is largely overlooked in the international development agenda, with attention and funding only minimally increasing since 2015, despite well documented increases in public concern about pollution and its effects on health.

The 2017 *Lancet* Commission on pollution and health documented that pollution control is highly cost-effective and, because pollution, climate change, and biodiversity loss are closely linked, actions taken to control pollution have a high potential to also mitigate the effects of those other planetary threats, thus producing a double or even a triple benefit.

We present specific recommendations for pollution and health, building on the earlier recommendations in the *Lancet* Commission on pollution and health.

International organisations and national governments need to continue expanding the focus on pollution as one of the triumvirate of global environmental issues, alongside climate change and biodiversity. We encourage the use of the health dimension as a key driver in policy and investment decisions, using available GBD information.

Affected countries must focus resources on addressing air pollution, lead pollution, and chemical pollution, which are the key issues in modern pollution. A massive rapid transition to wind and solar energy will reduce ambient air pollution in addition to slowing down climate change.

Private and government donors need to allocate funding for pollution management to support HPAP prioritisation processes, monitoring, and programme implementation. ODA support should involve LMICs in setting priorities through these processes.

All sectors need to integrate pollution control into plans to address other key threats such as climate, biodiversity, food, and agriculture. All sectors need to support a stronger stand on pollution in planetary health, OneHealth, and energy transition work.

International organisations need to establish an SPI for pollution, similar to those for climate and biodiversity, initially for chemicals, waste, and air pollution.

International organisations need to revise pollution tracking for the SDGs to correctly represent the effect of chemicals pollution including heavy metals. The reporting systems should allow burden of disease estimates to be used in the absence of national data.

International organisations and national governments need to invest in generating data and analytics to underpin evidence-based interventions to address environmental health risks. Priority investments should include the establishment of reliable ground-level air quality monitoring networks, along with lead baseline and monitoring systems, and other chemical monitoring systems.

International organisations and national governments need to use uniform and appropriate sampling protocols to collect evidence on exposure to hazardous chemicals such as lead, mercury, or chromium, which can be compared or generalised across LMICs.

Contributors

RF and PJL developed the concept and objectives for the Review. All authors contributed to the identification of key issues and writing of the Review.

Declaration of interests

MB reports institutional support from the Bill & Melinda Gates Foundation; JH also reports consulting fees from the German Ministry of Environment to develop ideas for advancing the Strategic Approach to Chemicals Management process; and JH reports fees from the UK Department for Environment, Food & Rural Affairs for teaching workshops. HH reports grants from the US National Institutes of Health for neuro-epidemiological research on the developmental neurotoxicity of pollutants; HH also reports consultant fees to law firms on cases related to the developmental neurotoxicity of pollutants; and HH serves as Chair of the Scientific Advisory Board of the Marilyn Brachman Hoffman Foundation and is a member of the Advisory Board for Physicians for Human Rights. PJL reports grants and contracts from the Centre Scientifique de Monaco, UN Environment, and the Barr Foundation, and consulting fees from the Centre Scientifique de Monaco; and PJL serves as President of the Collegium Ramazzini, Chair of the Scientific

Advisory Board of the Collegium Ramazzini, and Treasurer for the Consortium of Universities for Global Health. BL reports grants from the US National Institutes of Health, Canadian Institutes of Health, and US Department of Housing and Urban Development for research projects and personal consulting to study the effects of toxic chemicals on human health; BL also served as an expert witness in cases related to lead and fluoride poisoning in the USA and Canada but received no personal compensation for these services; and his expert witness fees are deposited in a research and training fund at Simon Fraser University (Burnaby, BC, Canada). All other authors declare no competing interests.

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References

1 Landrigan PJ, Fuller R, Acosta NJR, et al. The *Lancet* Commission on pollution and health. *Lancet* 2018; **391:** 462–512.

2 Murray CJL, Lopez AD. Evidence-based health policy--lessons from the Global Burden of Disease Study. *Science* 1996; **274:** 740–43.

3 Murray CJL, Aravkin AY, Zheng P, et al. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet* 2020; **396:** 1223–49.

4 UN Environment Programme. Global chemicals outlook II: from legacies to innovative solutions: implementing the 2030 Agenda for Sustainable Development. Geneva: United Nations Environment Porgramme 2019. https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/policy-and-governance/global-chemicals-outlook (accessed March 15, 2022).

5 Parvez SM, Jahan F, Brune M-N, et al. Health consequences of exposure to e-waste: an updated systematic review. *Lancet Planet Health* 2021; **5:** e905–20.

6 Institute for Health Metrics and Evaluation. 2019 Global Burden of Disease results tool. 2020. http://ghdx.healthdata.org/gbd-results-tool (accessed April 19, 2022).

7 Katoto PDMC, Byamungu L, Brand AS, et al. Ambient air pollution and health in sub-Saharan Africa: current evidence, perspectives and a call to action. *Environ Res* 2019; **173:** 174–88.

8 Fisher S, Bellinger DC, Cropper ML, et al. Air pollution and development in Africa: impacts on health, the economy, and human capital. *Lancet Planet Health* 2021; **5:** e681–88.

9 Southerland VA, Brauer M, Mohegh A, et al. Global urban temporal trends in fine particulate matter ($PM_{2.5}$) and attributable health burdens: estimates from global datasets. *Lancet Planet Health* 2022; **6:** e139–46.

10 Shaffer RM, Sellers SP, Baker MG, et al. Improving and expanding estimates of the global burden of disease due to environmental health risk factors. *Environ Health Perspect* 2019; **127:** 105001.

11 Lanphear BP, Rauch S, Auinger P, Allen RW, Hornung RW. Low-level lead exposure and mortality in US adults: a population-based cohort study. *Lancet Public Health* 2018; **3:** e177–84.

12 Chowdhury R, Ramond A, O'Keeffe LM, Shahzad S, Kunutsor SK, Muka T et al. Environmental toxic metal contaminants and risk of cardiovascular disease: systematic review and meta-analysis. *BMJ* 2018; **362:** k3310.

13 Ericson B, Hu H, Nash E, Ferraro G, Sinitsky J, Taylor MP. Blood lead levels in low-income and middle-income countries: a systematic review. *Lancet Planet Health* 2021; **5:** e145–53.

14 UNICEF and Pure Earth. The toxic truth: children's exposure to lead pollution undermines a generation of future potential. New York: UNICEF and Pure Earth, 2020. https://www.unicef.org/reports/toxic- truth-childrens-exposure-to-lead-pollution-2020 (accessed April 7, 2022).

15 Lanphear BP, Hornung R, Khoury J, et al. Erratum: low-level environmental lead exposure and children's intellectual function: an international pooled analysis. *Environ Health Perspect* 2019; **127:** 99001.

16 Ericson B, Landrigan P, Taylor MP, Frostad J, Caravanos J. The global burden of lead toxicity attributable to informal used lead-acid battery sites. *Ann Glob Health* 2016; **82:** 686–99.

17 Daniell WE, Van Tung L, Wallace RM, et al. Childhood lead exposure from battery recycling in Vietnam. *BioMed Res Int* 2015; **2015:** 193715.

18 van der Kuijp TJ, Huang L, Cherry CR. Health hazards of China's lead-acid battery industry: a review of its market drivers, production processes, and health impacts. *Environ Health* 2013; **12:** 61.

19 Forsyth JE, Nurunnahar S, Islam SS, et al. Turmeric means "yellow" in Bengali: lead chromate pigments added to turmeric threaten public health across Bangladesh. *Environ Res* 2019; **179:** 108722.

20 Forsyth JE, Saiful Islam M, Parvez SM, et al. Prevalence of elevated blood lead levels among pregnant women and sources of lead exposure in rural Bangladesh: a case control study. *Environ Res* 2018; **166:** 1–9.

21 Pantic I, Tamayo-Ortiz M, Rosa-Parra A, et al. Children's blood lead concentrations from 1988 to 2015 in Mexico City: the contribution of lead in air and traditional lead- glazed ceramics. *Int J Environ Res Public Health* 2018; **15:** E2153.

22 Téllez-Rojo MM, Bautista-Arredondo LF, Trejo-Valdivia B, et al. National report of blood lead levels and lead-glazed ceramics use in vulnerable children. *Salud Pública Méx* 2019; **61:** 787–97 (in Spanish).

23 O'Connor D, Hou D, Ok YS, Lanphear BP. The effects of iniquitous lead exposure on health. *Nat Sustain* 2020; **3:** 77–79.

24 The Intergovernmental Panel on Climate Change. Climate Change 2021: the physical science basis: contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press. 2021. https://www.ipcc.ch/report/ar6/wg1/#FullReport (accessed March 17, 2022).

25 Ocko I, Sun T, Shindell D, et al. Acting rapidly to deploy readily available methane mitigation measures by sector can immediately slow global warming. *Environ Res Lett* 2021; **16:** 054042.

26 UN Environment Programme. Global methane assessment: benefits and costs of mitigating methane emissions. Geneva: UN Environment Programme, 2021. https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emission (accessed March 17, 2022).

27 Klimont Z, Kupiainen K, Heyes C, et al. Global anthropogenic emissions of particulate matter including black carbon. *Atmos Chem Phys* 2017; **17:** 8681–723.

28 Brand C. Beyond 'dieselgate': implications of unaccounted and future air pollutant emissions and energy use for cars in the United Kingdom. *Energy Policy* 2016; **97:** 1–12.

29 US Environmental Protection Agency Office of Research and Development. Black carbon emissions from residential wood combustion appliances Feb 2020. 2020. https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=CEMM&dirEntryId=348245 (accessed March 20, 2022).

30 Liu Y, Tong D, Cheng J, et al. Role of climate goals and clean-air policies on reducing future air pollution deaths in China: a modelling study. *Lancet Planet Health* 2022; **6:** e92–99.

31 Grandjean P, Landrigan PJ. Neurobehavioural effects of developmental toxicity. *Lancet Neurol* 2014; **13:** 330–38.

32 Ho S-M, Johnson A, Tarapore P, Janakiram V, Zhang X, Leung Y-K. Environmental epigenetics and its implication on disease risk and health outcomes. *ILAR J* 2012; **53:** 289–305.

33 Grandjean P, Abdennebi-Najar L, Barouki R, et al. Timescales of developmental toxicity impacting on research and needs for intervention. *Basic Clin Pharmacol Toxicol* 2019; **125** (suppl 3)**:** 70–80.

34 Levine H, Jørgensen N, Martino-Andrade A, et al. Temporal trends in sperm count: a systematic review and meta-regression analysis. *Hum Reprod Update* 2017; **23:** 646–59.

35 Grandjean P, Heilmann C, Weihe P, Nielsen F, Mogensen UB, Budtz-Jørgensen E. Serum vaccine antibody concentrations in adolescents exposed to perfluorinated compounds. *Environ Health Perspect* 2017; **125:** 077018.

36 Dalsager L, Christensen N, Halekoh U, et al. Exposure to perfluoroalkyl substances during fetal life and hospitalization for infectious disease in childhood: a study among 1,503 children from the Odense Child Cohort. *Environ Int* 2021; **149:** 106395.

37 Grandjean P, Timmermann CAG, Kruse M, et al. Severity of COVID-19 at elevated exposure to perfluorinated alkylates. *PLoS One* 2020; **15:** e0244815.

38 Chen Z, Huang BZ, Sidell MA, et al. Near-roadway air pollution associated with COVID-19 severity and mortality—multiethnic cohort study in southern California. *Environ Int* 2021; **157:** 106862.

39 Park SK, Sack C, Sirén MJ, Hu H. Environmental cadmium and mortality from influenza and pneumonia in U.S. adults. *Environ Health Perspect* 2020; **128:** 127004.

40 Germolec D, Luebke R, Rooney A, Shipkowski K, Vandebriel R, van Loveren H. Immunotoxicology: a brief history, current status and strategies for future immunotoxicity assessment. *Curr Opin Toxicol* 2017; **5:** 55–59.

41 Dentener F, Keating T, Akimoto H, Pirrone N, Dutchak S, Zuber A. Convention on Long-range Transboundary Air Pollution, UN, UNECE Task Force on Emission Inventories and Projections. Hemispheric transport of air pollution 2010: prepared by the Task Force on Hemispheric Transport of Air Pollution acting within the framework of the Convention on Long-range Transboundary Air Pollution. https://digitallibrary.un.org/record/706400?ln=en (accessed April 19, 2022).

42 Travnikov O, Batrakova N, Gusev A, et al. Assessment of transboundary pollution by toxic substances: heavy metals and POPs (EMEP Status Report 2/2020). Brussels: European Commission, 2020. https://www.nilu.com/pub/1821637/ (accessed March 20, 2022).

43 Zhang Q, Jiang X, Tong D, et al. Transboundary health impacts of transported global air pollution and international trade. *Nature* 2017; **543:** 705–09.

44 Lafontaine S, Schrlau J, Butler J, et al. Relative influence of trans-Pacific and regional atmospheric transport of PAHs in the Pacific northwest, U.S. *Environ Sci Technol* 2015; **49:** 13807–16.

45 Moran D, Kanemoto K. Tracing global supply chains to air pollution hotspots. *Environ Res Lett* 2016; **11:** 094017.

46 Guan D, Su X, Zhang Q, et al. The socioeconomic drivers of China's primary PM2.5 emissions. *Environ Res Lett* 2014; **9:** 024010.

47 Bosch AC, O'Neill B, Sigge GO, Kerwath SE, Hoffman LC. Heavy metals in marine fish meat and consumer health: a review. *J Sci Food Agric* 2016; **96:** 32–48.

48 Ma C, Liu F, Hu B, Wei M, Zhao J, Zhang H. Quantitative analysis of lead sources in wheat tissue and grain under different lead atmospheric deposition areas. *Environ Sci Pollut Res Int* 2019; **26:** 36710–19.

49 Maddela NR, Kakarla D, García LC, Chakraborty S, Venkateswarlu K, Megharaj M. Cocoa-laden cadmium threatens human health and cacao economy: a critical view. *Sci Total Environ* 2020; **720:** 137645.

50 Winiarska-Mieczan A, Kiczorowska B. Determining the content of lead and cadmium in infant food from the Polish market. *Int J Food Sci Nutr* 2012; **63:** 708–12.

51 Sirot V, Traore T, Guérin T, et al. French infant total diet study: exposure to selected trace elements and associated health risks. *Food Chem Toxicol* 2018; **120:** 625–33.

52 Dabeka R, Fouquet A, Belisle S, Turcotte S. Lead, cadmium and aluminum in Canadian infant formulae, oral electrolytes and glucose solutions. *Food Addit Contam Part A Chem Anal Control Expo Risk Assess* 2011; **28:** 744–53.

53 Gardener H, Bowen J, Callan SP. Lead and cadmium contamination in a large sample of United States infant formulas and baby foods. *Sci Total Environ* 2019; **651:** 822–27.

54 World Bank. The global health cost of ambient PM2.5 air pollution: a case for action beyond 2021. Washington, DC: The World Bank. 2021. https://openknowledge.worldbank.org/handle/10986/36501 (accessed Feb 4, 2022).

55 Pandey A, Brauer M, Cropper ML, et al. Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. *Lancet Planet Health* 2021; **5:** e25–38.

56 Feenstra RC, Inklaar R, Timmer MP. The next heneration of the Penn World Table. *Am Econ Rev* 2015; **105:** 3150–82.

57 The World Bank. World development indicators. Washington, DC: The World Bank. 2022. https://databank.worldbank.org/source/world-development-indicators (accessed Dec 10, 2021).

58 WHO. Global action plan for the prevention and control of NCDs 2013-2020. Geneva: World Health Organization, 2013.

59 WHO. Guideline for clinical management of exposure to lead. Geneva: World Health Organization. https://www.who.int/publications/i/item/9789240037045 (accessed April 7, 2022).

60 Zhang J, Jiang H, Zhang W, et al. Cost-benefit analysis of China's action plan for air pollution prevention and control. *Front Eng Manag* 2019; **6:** 524–37.

61 Clean Air Asia. China Air 2020—air pollution prevention and control progress in Chinese cities. Beijing: Clean Air Asia, 2020. https://cleanairasia.org/china-air-2020/ (accessed April 13, 2021).

62 WHO. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. 2021. Geneva: World Health Organization. https://apps.who.int/iris/han- dle/10665/345329 (accessed April 7, 2022).

63 UN Environment Programme. For people and planet: the United Nations Environment Programme strategy for 2022–2025 to tackle climate change, loss of nature and pollution. Nairobi, Kenya: United Nations Environment Programme, 2021.

64 World Bank. Clearing the air: a tale of 3 cities. New York: World Bank, 2020. https://openknowledge.worldbank.org/handle/10986/34757 (accessed Nov 16, 2020).

65 European Commission. Zero Pollution Action Plan: towards zero pollution for air, water and soil. 2021. https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en (accessed April 5, 2022).

66 Swinehart S, Fuller R, Kupka R, Conte MN. Rethinking aid allocation: analysis of official development spending on modern pollution reduction. *Ann Glob Health* 2019; **85:** 132.

67 Clean Air Fund. The state of global air quality funding. London: Clean Air Fund, 2021. https://www.cleanairfund.org/wp-content/uploads/2021/09/The-State-of-Global-Air-Quality-Funding-2021-report-compressed-2.pdf (accessed Jan 7, 2022).

68 Johnson P. Global Philanthropy Report: perspectives on the global foundation sector. Hauser Institute for Civil Society at Harvard University. Boston: Hauser Institute, 2018. https://cpl.hks.harvard.edu/global-philanthropy-report-perspectives-global-financial-sector (accessed Jan 7, 2022).

69 Health Effects Institute and Institute for Health Metrics and Evaluation. State of global air 2020: a special report on global air exposure and its health impacts. Boston: Health Effects Institute. https://www.stateofglobalair.org/ (accessed July 17, 2021).

70 Yin P, Brauer M, Cohen AJ, et al. The effect of air pollution on deaths, disease burden, and life expectancy across China and its provinces, 1990–2017: an analysis for the Global Burden of Disease Study 2017. *Lancet Planet Health* 2020; **4:** e386–98.

71 Ganguly T, Selvaraj KL, Guttikunda SK. National Clean Air Programme (NCAP) for Indian cities: review and outlook of clean air action plans. *Atmos Environ* 2020; **8:** 100096.

72 Health Effects Institute. How does your air measure up against the WHO Air Quality Guidelines? A state of global air special analysis. Boston, MA: Health Effects Institute, 2022.

73 Pinder RW, Klopp JM, Kleiman G, Hagler GSW, Awe Y, Terry S. Opportunities and challenges for filling the air quality data gap in low- and middle-income countries. *Atmos Environ* 2019; **215:** 116794.

74 Martin RV, Brauer M, van Donkelaar A, Shaddick G, Narain U, Dey S. No one knows which city has the highest concentration of fine particulate matter. *Atmos Environ* 2019; **3:** 100040.

75 Makoni M. Air pollution in Africa. *Lancet Respir Med* 2020; **8:** 60–61.

73 Alvarado MJ, McVey AE, Hegarty JD, et al. Evaluating the use of satellite observations to supplement ground-level air quality data in selected cities in low- and middle-income countries. *Atmos Environ* 2019; **218:** 117016.

77 Téllez-Rojo MM, Bautista-Arredondo LF, Trejo-Valdivia B, et al. Reporte nacional de niveles de plomo en sangre y uso de barro vidriado en población infantil vulnerable. *Salud Publica Mex* 2019; **61:** 787–97.

78 Kazzi Z, Gabelaia L, Shengelia L, et al. Lessons learned through the journey of a medical toxicologist while characterizing lead hazards in the Republic of Georgia. *J Med Toxicol* 2020; **16:** 3–5.

79 Zhang Y, O'Connor D, Xu W, Hou D. Blood lead levels among Chinese children: the shifting influence of industry, traffic, and e-waste over three decades. *Environ Int* 2020; **135:** 105379.

80 Kordas K, Ravenscroft J, Cao Y, McLean EV. Lead exposure in low and middle-income countries: perspectives and lessons on patterns, injustices, economics, and politics. *Int J Environ Res Public Health* 2018; **15:** 2351.
81 UNICEF, Pure Earth, Clarios Foundation. Protecting every child's potential. 2020. https://www.protectingeverychildspotential.org/ (accessed March 12, 2022).
82 UN and World Bank. Making every drop count: an agenda for water action. High-level panel on water outcome document. Geneva: United Nations, 2018. https://sustainabledevelopment.un.org/content/documents/17825HLPW_Outcome.pdf (accessed Jan 11, 2021).
83 UN Water. Progress on ambient water quality—piloting the monitoring methodology and initial findings for SDG 6 indicator 6.3.2. New York: United Nations, 2019. https://www.unwater.org/publications/progress-on-ambient-water-quality-632/ (accessed Jan 11, 2021).
84 UNICEF and WHO. Progress on household drinking water, sanitation and hygiene 2000–2017: special focus on inequalities. New York: UNICEF, 2019. https://www.who.int/water_sanitation_health/publications/jmp-report-2019/en/ (accessed Jan 11, 2021).
85 UN Water. SDG 6 synthesis report 2018 on water and sanitation. New York: United Nations, 2018. https://www.unwater.org/publications/highlights-sdg-6-synthesis-report-2018-on-water-and-sanitation-2/ (accessed Jan 11, 2021).
86 Krewski D, Andersen ME, Tyshenko MG, et al. Toxicity testing in the 21st century: progress in the past decade and future perspectives. *Arch Toxicol* 2020; **94:** 1–58.
87 UN Environment Programme. An assessment report on issues of concern: chemicals and waste issues posing risks to human health and the environment. Geneva: United Nations Environment Programme, 2020. https://wedocs.unep.org/bitstream/handle/20.500.11822/33807/ARIC.pdf?sequence=1&isAllowed=y (accessed Jan 5 2021).
88 SAICM Knowledge. Ministers pledge funding, commitment for chemicals action. 2020. https://saicmknowledge.org/library/ministers-pledge-funding-commitment-chemicals-action (accessed Jan 7, 2022).
89 Global Alliance on Health and Pollution. Health and pollution action plans. Geneva: Global Alliance on Health and Pollution, 2021. https://gahp.net/planning-health-pollution-action-plans/ (accessed Feb 1, 2021).
90 Fuller R, Rahona E, Fisher S, et al. Pollution and non-communicable disease: time to end the neglect. *Lancet Planet Health* 2018; **2:** e96–98.
91 World Bank Group. Open knowledge repository: country strategy documents. 2022. https://openknowledge.worldbank.org/handle/10986/23098 (accessed Dec 10, 2021).
92 Inter-American Development Bank. Country strategies. https://www.iadb.org/en/about-us/country-strategies (accessed Dec 10, 2021).
93 African Development Bank. Country strategy papers. https://www.afdb.org/en/documents/project-operations/country-strategy (accessed Dec 10, 2021).
94 Asian Development Bank. Country partnership strategies. https://www.adb.org/documents/series/country-partnership-strategies (accessed Dec 10, 2021).
95 UN Sustainable Development Group. Sustainable Development Goals. https://uninfo.org/documents (accessed Dec 10, 2021).
96 Independent Evaluation Group. Toward a clean world for all: an IEG evaluation of the World Bank group's support to pollution management. New York: Independent Evaluation Group, 2017. http://ieg.worldbankgroup.org/sites/default/files/Data/Evaluation/files/pollutionmanagement.pdf (accessed Jan 7, 2022).

Supplementary Materials: Progress on Pollution

The 2017 Lancet Commission on Pollution and Health generated more than 1500 articles about the health effects of pollution in the popular press and was referenced extensively in the scientific literature.[1] We examine the extent to which this increased popular and scientific awareness of pollution and its health effects has translated into progress against pollution over the past four years.

We find that in some countries, such as China, growing scientific awareness of pollution's dangers has generated substantial growth in national expenditures for pollution control and led to significant progress in prevention of pollution-related disease. Overall, this review shows mixed rather than robust advances.

Progress on ambient air pollution

Ambient air pollution has multiple sources. These include point sources such as power plants and industrial complexes, as well as more diffuse sources including traffic-related air pollution, agricultural and other open-burning practices, and dust, both natural and anthropogenic; natural dust, mainly crustal dust, has been reported to contribute up to one-third of the $PM_{2.5}$ load in some cities.[2,3] Household sources, the primary cause of Household Air Pollution (HAP) also contribute to ambient air pollution.

The world's highest ambient $PM_{2.5}$ levels – on a population-weighted average – are seen in India, closely followed by Nepal. Other areas of great concern are Bangladesh and Pakistan, which both also have very high $PM_{2.5}$ pollution levels. China, which until the last decade also had very high levels of ambient air pollution has recently made significant progress.[4]

India. Air pollution was responsible for 1·67 million deaths in India in 2019 - 17·8 percent of all deaths in the country, the largest number of air-pollution-related deaths of any country in the world.[5] The majority of these deaths – 0·98 million - were caused by ambient $PM_{2.5}$ pollution. Another 0·61 million were due to household air pollution.

Air pollution is most severe in the Indo-Gangetic Plain (northern India), where topography and meteorology concentrate pollution from energy, mobility, industry, agriculture, and other activities. It is home to hundreds of millions of people. This area also contains New Delhi and many of the most polluted cities.[5] Burning of biomass in households was the single largest cause of air pollution deaths in India, followed by coal combustion and crop burning. Population-weighted mean exposure to ambient air pollution peaked nationally in India at 95mg/m3 in 2014, was reduced to 82mg/m3 by 2017, but more recently has been rising slowly again.[5]

India has developed a range of instruments for tackling air pollution, including a National Clean Air Program, and in 2019 launched a Commission for Air Quality Management in the National Capital Region.[6] State Pollution Control Boards have regulatory powers to impose and enforce emissions standards on pollution sources. However, India does not have a strong centralized administrative system to drive its air pollution control efforts and consequently improvements in overall air quality have been limited and uneven.[7] Public interest litigation and actions by the Supreme Court have been instrumental in pushing action on critical pollution issues. A number of cities in India are making progress, particularly in establishing air quality monitoring systems and local level planning.[8] In recent years, these cities have seen some substantial improvements in air quality, but across more than 90 percent of the country ambient air pollution levels remain well above the WHO guideline for $PM_{2.5}$ pollution of 10 μg/m3.[9]

China. China has had air pollution control measures in place since the 1970s, and Beijing City has been controlling individual large point sources of pollution such as power plants since that time, but progress against pollution was initially slow. However, beginning approximately a decade ago, Beijing and Shanghai, inspired by planning for the 2008 Olympics and the 2010 World Expo, took the lead in addressing air pollution.

In 2013, severe episodes of pollution in major cities caused wide public concern, and the Chinese government responded by launching a "battle for blue skies". A key breakthrough was the recognition that about one-third of the pollution in major cities was from regional sources outside the cities' jurisdiction. Accordingly, a cross-jurisdictional Regional Coordination Group was established in 2013 and then in 2018, the State Council, at the central level, elevated the administrative status of the group to include national ministries. At the same time, the central government established and implemented a Five-Year National Air Quality Action Plan (2013-2018). Funding for this plan totaled about RMB1.65 trillion (US$244 billion in 2017 dollars). Under this plan, effective interventions against pollution were undertaken in the major urban airsheds of Beijing-Tianjin-Hebei, the Pearl River Delta, and the Yangtze River Delta. This was followed by a Three-Year Plan (2018-2020), which continues to be updated, with increasing focus on those cities and regions that have not made sufficient progress. The health benefits of this investment are estimated to have been 1.5 times the cost.[10]

Due to these extensive efforts, ambient $PM_{2.5}$ pollution and household air pollution from the burning of solid fuels have decreased markedly in China.[11] The Beijing region has made noteworthy progress since the inception of the National Air Quality Action Plans, and average mean $PM_{2.5}$ levels have dropped by nearly 40 percent as against a Plan target of 25 percent.[12] While these are remarkable improvements, $PM_{2.5}$ concentrations in Beijing are still above both Chinese standards and WHO guidelines. Across the country, mean population-weighted $PM_{2.5}$ exposures were reduced to about 48ug/m^3 in 2019, down from a peak of 63ug/m^3 in 2013.[4] Despite these gains, 81 percent of China's population still lives in regions where air pollution levels exceed the WHO Interim Target 1.[13] The least-cost actions against air pollution have now mainly been taken in China. Further progress will require more finance and more innovative approaches.

Mexico. Mexico City grew very rapidly in the 1980s and 1990s, with sharp increases in population, industrialization, and motorization. This growth resulted in hazardous levels of air pollution, with daily particulate levels (measured as PM_{10}) peaking at about 300mg/m^3 on occasions. In 1990, facing a public health crisis, the Federal Government set up a cross-sectoral Working Group which developed an Integrated Program against Atmospheric Pollution 1990-94 for the wider metropolitan area, comprising Mexico City and 17 adjacent municipalities.

Mobile sources – cars, trucks, and buses - are the main contributors to air pollution in the Mexico City metropolitan area, with emissions inventories showing that over 50 percent of the primary $PM_{2.5}$ emissions consistently come from these sources.[14] Key interventions under a series of programs have therefore concentrated on addressing transportation through actions such as imposing fuel quality standards for vehicles and for other industrial engines; control technologies for vehicles; and testing requirements for cars. More recent actions have included stricter fuel and emissions standards and upgrading the informal microbus systems including the construction of a large-scale Bus Rapid Transit

(BRT) network. Controls have also been placed on industrial emissions and efforts are focusing more on cooking with fuelwood and on agricultural burning.

These coordinated efforts across the metropolitan area, including a significant public information and involvement component, have reduced particulate pollution levels from 1990s levels, especially in terms of daily peak episodes. Mexico has continued to strengthen its air quality monitoring and has recently established regulations to help address the health impacts of air pollution by standardizing air quality monitoring systems and communication of results to the public. These regulations also provide support to government agencies at various levels to compile and analyze air quality and health data and to publish results.[15] Expanded financial assistance is being prepared to support agencies in implementing these norms.

Progress in African Cities

Africa now contains three of the world's megacities, with populations estimated at over ten million, in Cairo, Egypt; Kinshasa, DR Congo; and Lagos, Nigeria. Lagos, a coastal city of 24 million people, exemplifies how air pollution is undermining the growth and health of Africa's megacities. Road transport is the main source of ambient air pollution in Lagos. Most vehicles are over 15 years old, using outdated emission control technologies and burning fuel with high sulfur levels - 200 times higher than U.S. standards for diesel. Industrial emissions from cement, chemicals, furniture, and steel industries are the second leading source of air pollution in Lagos. Generators supply half of Lagos' total energy demand and are the third source of air pollution. The incomplete combustion of gasoline and oil used to operate generators results in heavy air pollution. Artisanal refineries in the oil-rich Niger Delta also contribute to episodic air pollution in local areas.[16] Lagos has recorded $PM_{2.5}$ levels as high as 68 $\mu g/m^3$, concentrations far above the WHO air quality guideline of 10 $\mu g/m^3$, and in the same range as those recorded other polluted megacities in Africa such as Cairo (76 $\mu g/m^3$). Illness and premature deaths due to ambient air pollution were responsible for economic losses of $2.1 billion in 2018 in Lagos State, representing about 2.1 percent of the state's GDP.[17] Artisanal refineries in the oil-rich Niger Delta contribute to episodic air pollution in those areas of Nigeria.[16]

The rapid annual growth of the largest African cities continues, but is slowing, and now the fastest urban growth is taking place not in megacities but in large "secondary cities."[18] These growing urban areas are affected by a wide variety of air pollution sources: biomass burning for domestic and commercial uses; traffic (old vehicles using dirty fuel); agricultural burning and wildfires; waste burning; and small-scale industry.

Reliable data on air quality across Africa, however, is limited. In the WHO urban air quality database, 41 cities in twelve Sub-Saharan countries reported their data.[19] Currently only 7 of 54 African countries have reliable real time air quality monitoring, although steadily improving satellite imaging and analysis is helping to fill the voids.[20,21] South Africa and Senegal have established continuous air quality monitoring systems and other countries, including Ghana and Nigeria, have carried out monitoring programs at intervals, though funding for maintenance and quality control is sporadic.

More detailed epidemiological and technical studies and analysis are needed in African cities to assess and quantify the health impacts of air pollution. While innovative approaches such as examining historical records of visibility at airports near urban areas (Addis Ababa, Nairobi and Kampala) have demonstrated declines in air quality over recent decades, more consistent data are needed to support interventions.[20,21] A practical and effective approach in a city might comprise an integrated network made up of a reference grade ground monitoring station that can improve the accuracy of satellite measurements and linked to lower-cost air monitors to detect hotpots and identify temporal variations.[22] Kampala and Nairobi are examples of cities that are moving in this direction.

Despite challenges such as traffic congestion, some African cities are working to reduce ambient air pollution. Several African countries are working to upgrade transport fuel quality where dirty diesel is still predominant. West African countries have recently pledged to introduce cleaner fuels and vehicle standards across the region.[23, 24] Some counties have made considerable progress, although implementation of clean fuel regulations has been patchy, with Nigeria, the biggest country in the region, not yet fully controlling high sulfur fuel imports.[25] There is also growing attention to the problem of used vehicle exports from Europe, the USA, and Japan to countries with few or no regulatory controls on CO^2 and $PM_{2.5}$ emissions. While some countries, such as Morocco, Tunisia, and Côte d'Ivoire have strong regulatory controls and prohibit import of vehicles older than 5 years, many others, particularly in Western and sub-Saharan Africa, have little or no controls on vehicle emissions or age, resulting in higher levels of climate-driving emissions as well as road safety issues.[26]

Another positive sign for air quality in Africa is the consistent decline in levels of nitrogen dioxide (NO_2), a harmful[27] air pollutant, across the northern region of Sub-Saharan Africa. This decline is a marker for reduced agricultural burning. Satellite observations show that NO_2 concentrations during the biomass burning season in the northern fire region declined by 4·5 percent between 2005 and 2017, potentially benefitting hundreds of millions of people.[28]

Other Metropolitan Areas. Progress against air pollution has been variable in cities and countries across the world depending on a range of local geographical, political, and financial factors. In South America, some cities such as Santiago de Chile and Bogota, Colombia have made major improvements in air quality. In Santiago, the Chilean government has acknowledged the severity of the air pollution problem and is collecting real-time information, monitoring air pollution levels, and implementing interventions.

In Asia, Bangkok has been able to reduce notoriously poor air quality through a range of interventions, driven by high-level political commitment.[29] Progress against air pollution in many low-income and middle-income countries, including many highly populated secondary cities in China and India, has been mixed and is limited by low levels of human and financial resources.

Lessons Learned

A World Bank summary report reviewing ambient air pollution control efforts in major cities around the world reached a simple and clear conclusion about measures to address air pollution:

"There is no silver bullet, and air pollution will only be tackled through sustained political commitment. Information, incentives and institutions are the three prongs of an effective air pollution management strategy for any country."[14]

Monitoring of air pollution levels is fundamental to pollution control. Adequate and reliable air quality data are essential for effective decision making and for tracking progress resulting from interventions. In Europe and North America, nearly all urban areas have some reference grade ambient air quality monitoring stations and larger cities have a dozen or more. This represents about one monitor per 100-600,000 residents. By contrast, across Sub-Saharan Africa, there is just one ground-level monitor per

15.9 million people.[30,31] This low coverage is inadequate for calibration of air quality data based on remote sensing approaches and for the support of local initiatives to control pollution.

Effective interventions need to be developed in the context of a broad air quality planning process which involves all the relevant local jurisdictions and all the sectors within and beyond government that are in a position to influence outcomes. Basic information needs to be developed through source apportionment studies and information of pollution sources needs to be complemented by computer modelling that includes local conditions of meteorology and geography. Urban air pollution sources do not respect administrative boundaries, especially considering rural and agricultural air pollution sources, such as crop burning. An "airshed" approach is essential.[32]

Household Air Pollution (HAP)

The combustion of biomass fuels for household cooking and heating exposes more than 40 percent of the world's population to household air pollution.[33] Efforts in recent decades to reduce household air pollution by upgrading crude cooking stoves have resulted in more people having access to cleaner fuels, and the proportion of the global population with access to clean fuels and technologies inched up from 56 to 63 percent between 2010 and 2018. However, because of population increases these gains have produced only small net reductions in the numbers of people exposed to high levels of household pollution.[34] The number of people without access to clean fuels thus remains at about 3 billion.[33]

China. China has shown significant progress against household air pollution, with total deaths dropping from about 790,000 in 1990 to 271,000 in 2017 – a fall of two-thirds.[35] Much of this improvement appears to be due to reduced household solid fuel use resulting from rapid urbanization and rising incomes.[36] Rural areas have also undergone residential energy transitions, reducing both residential emissions and overall air pollution.[37]

India. Risk management for air quality in India has been challenging because of the ubiquity and magnitude of exposures attributable to ambient and household sources, that often straddle rural-urban boundaries.[38] To address this complexity, India has rolled out one of the world's most ambitious upscaling of clean cooking fuels through the Pradhan Mantri Ujjwala Yojana (PMUY) program, that over the past 5 years has provided nearly 80 million households access to liquefied petroleum gas (LPG).[39] Increased access and use of LPG is expected to accelerate the reduction of health burden attributable to household air pollution. Multiple recent studies report large contributions (ranging from 22-52 percent) from solid cooking fuel use to ambient $PM_{2.5}$.[40] The PMUY thus affords an unprecedented opportunity to achieve co-benefits for both ambient and household air pollution. As drivers of sustained LPG use are recognized and addressed, an ongoing rural exposure surveillance mechanism (similar to what is available for ambient air quality in cities) could allow the PMUY program to become a major catalyst for air quality actions in the country, while also creating seamless, clean breathing spaces for rural and urban populations.

Africa. Use of biomass for household fuel is a major issue across much of Africa, especially in rural areas where it accounts for about 90 percent of roundwood production, of which 16 percent is converted to charcoal. The African Union encourages the preparation of national strategies to address both household air pollution and deforestation, urging member states to focus on improved biomass production and consumption and on substitution of biomass energy by LPG and electricity.[41] Across Africa, however, and especially in rural areas, progress has been minimal. In Ethiopia, for example, with a population of over 100 million people, only 5 percent have access to clean fuel, despite increasing efforts by the government to enhance access.[42]

The main reasons for the limited success in reducing household air pollution include the costs of the new systems, inability to make or afford repairs to the new systems, lack of reliable access to cleaner fuels, and the continued use of "fuel stacking" where households will use more than one type of fuel or cooking technology, both to provide choice and as insurance against problems with any one system.[43] There is increasing understanding of the importance of community and sub-national factors as opposed to household characteristics as determinants of fuel-switching. A decade-long study of fuel-switching concluded that household characteristics such as size, wealth and education were strongly associated with fuel-switching in India, but community level factors were more relevant in eight other countries examined.[44]

A new approach aimed at accelerating progress toward access for households to modern cooking energy has been drafted by development partners, led by the Energy Sector Management Assistance Program (ESMAP) at the World Bank. This effort is under a Clean Cooking Fund launched in 2019 with initial support from several European governments and a funding target of $500 million with an ambition to leverage this to achieve $2 billion in investments in a transformed clean cooking market. The first investment under the Clean Cooking Fund is a $10 million contribution to a clean cooking project in Rwanda.

The Modern Energy Cooking Services (MECS) program is a five-year initiative (funded by the UK) which considers both technical and behavioral aspects. The MECS program estimates that to achieve universal access to improved cooking by 2030 (although not yet at the level of full access for everybody) would cost approximately $100 billion over the next decade.[45] For Sub-Saharan African, where much of the expenditure would be needed, it is estimated that governments would have to provide about 60 percent and households the balance.

Progress on Air Pollution and Climate Change

Climate change and air pollution are closely related, and it is now very clear that action should be taken to deal with both of these problems synergistically and that such action has high potential to produce co-benefits.[46] Practical interventions identified as addressing both problems and producing the greatest co-benefits include phasing out of fossil fuels for power production, wide-scale transition to clean renewable energy, increasing use of active transport – walking and cycling, increased use of electric vehicles, and increased use of public rather than private transportation.[29] There are also synergies between air pollution and climate change mitigation in food systems. Agricultural emissions such as methane (from animal agriculture among other sources) contribute to both warming and to health-damaging ozone formation. Other energy-intensive practices, such as the use of synthetic fertilizers, contribute to health secondary particulate matter formation when agricultural ammonia (crop burning and animal agriculture as well as fertilizer) combines with emissions from fossil fuel combustion. Agricultural emissions are a leading contributor to secondary particulate matter in the U.S., Europe, and parts of Asia.[47]

Major impediments to a transition from coal to cleaner, less polluting sources of energy are the wide availability of millions of tons of relatively cheap coal and the continuing promotion of coal burning for industrial use and power generation in low-income and middle-income by China and other coal-exporting countries.

There is potential to accelerate progress on air pollution and climate change through integrating the health co-benefits of decarbonisation into the Nationally Determined Contributions to GHG mitigation under the Paris Climate Agreement. At present, however, only a minority of countries quantify the health co-benefits of their GHG mitigation plans.[48] Actions to reduce short lived climate pollutants through fourteen measures to tackle methane and black carbon emissions can yield major benefits to health, averting 0·7 to 4·7 million annual premature deaths from ambient air pollution in 2030 and beyond and increasing annual crop yields by 30 to 135 million metric tons from ozone reductions.[49]

The contribution of renewable sources to global energy production continues to grow. Currently, wind/solar, hydropower, and nuclear together account about one third of global electricity production. The installed capacity of wind and solar combined has more than quadrupled since 2010, and is estimated to double again by 2025, at which point it will exceed global hydropower capacity. Nuclear energy's share of the global energy mix continues to slowly decline.[50]

The costs of producing electricity from wind and solar power have dropped dramatically in the past decade, and average costs of new solar photo-voltaic (PV) and wind power plants are now significantly lower than the costs of new fossil fuel plants on a long term averaged cost basis (using Levelised Cost of Electricity (LCOE)).[51,52] A basic obstacle to accelerating the switch to renewables is the long lifespan of existing coal fired plants. A large power plant can have an economic lifespan of 30-40 years if well maintained and operated, depending on fuel costs and other factors, and hundreds of millions of dollars are tied up in these plants. The longevity of new power plants emphasizes how important it is to make the best decisions now, for both climate mitigation and air quality.

Governmental investments in electric vehicles may be expected to pay for themselves many times over through reducing pollution-related disease and thus reducing health care costs and increasing economic productivity. However, enthusiasm for large-scale transition to renewables and to electric vehicles must be tempered by recognition of the potential environmental and social impacts of large wind, solar and hydro developments. Solar plants have large land areas requirements; major wind farms can impact land and coastal environments; batteries require extensive extraction of lead and rare earths; and hydropower plants have a long history of environmental and social challenges.[53–55] As for all major energy projects, careful analysis, consultation and assessment are required for good decision making.

Progress on Water, Sanitation and Hygiene (WASH)

Safe drinking water is fundamental to life and health. However, despite continued efforts over many decades and continuing improvements, inadequate Water, Sanitation and Hygiene (WASH) remains a major global risk factor for disease and premature death and has serious health and socio-economic consequences, particularly for women and girls especially in low-income and middle-income countries.[56] The importance of water and sanitation for development was recognized in the Millennium Development Goals (MDGs) and has subsequently been highlighted by the inclusion a specific Goal on WASH in the Sustainable Development Goals SDGs (SDG 6: Ensure Availability and Sustainable Management of Water and Sanitation for All).

Considerable expansion of access to clean water and sanitation services has been achieved in recent decades, but a 2018 review of progress towards the achievement of the targets set under the Sustainable Development Goals concluded that it would be an enormous challenge to close existing gaps in coverage by 2030.[57] A fundamental problem is that rapidly growing populations in low-income and middle-income countries often outstrip efforts to provide clean water and sanitation, with the result that the number of people worldwide lacking adequate access to these services remains high despite valiant efforts. Thus, about 1.8 billion people gained access to at least basic water services between 2000 and 2017, and yet the population using safely managed water services increased only from 61 to 71 percent. Likewise, in the same period, 2·1 billion people gained access to at least basic sanitation services, and yet the population using safely managed sanitation services increased only from 28 to 45 percent.[58] According to UN estimates, 2·2 billion people still lack access to safe drinking water and 4·2 billion lack safely managed sanitation services.[59]

In low-income and middle-income countries where organizational and financial resources are often limited, a range of options have been used to provide safe drinking water and sanitation services and move communities up the water and sanitation ladders. These include small-scale or community-level programs. Numerous bilateral and multilateral donors, NGOs and private organizations are involved in supporting local governments in designing and implementing appropriate local systems. Additionally, some water companies in rich countries encourage their customers to join them in improving WASH in low-income and middle-income countries.

Sustainable funding for water and hygiene must come from national and local resources, although multilateral and bilateral partners have provided considerable investment support and continue to support national and local governments. The World Bank Group provided $30 billion to client countries for clean water and sanitation services over the period 2007-2016.[60] Meeting the basic water and sanitation targets of SDG6 would require capital investment of an estimated $114 billion per year through 2030.[59]

The UN High Level Panel on Water specifically considered increases in investment and finance needed to provide safe drinking water and adequate sanitation worldwide and identified several necessary changes. These include improving governance and therefore creditworthiness; leveraging private capital; more efficient use of resources; and identifying permanent revenue streams for operations and maintenance, which would also improve the attractiveness of new investment.[56,61] The scale of the challenge calls for a new approach and a clear focus to achieve the ambitious 2030 targets established under the Sustainable development Gals. The UN High Level Panel on Water specifically calls for action to catalyze change, build partnerships and increase international cooperation as the core of a comprehensive agenda to achieve the sustainable development objectives.[56]

Assessments of the disease burden from water pollution in the past have focused mainly on diarrheal disease. More recently, estimates of the burden of disease and death attributable to water pollution have been revised upward as better understanding has developed of the wider health impacts of water pollution and the broad effectiveness of interventions. Recent work has, for example, estimated the impacts of inadequate access to clean water on the burden of such diseases as ascariasis, hookworm, schistosomiasis, and trachoma.[62] Chemical pollution of drinking water is an additional large and growing global problem. The health impacts of chemically contaminated drinking water are not quantified and almost certainly undercounted.

The Lancet Commission on WASH and Health, expected to report in 2022, is undertaking a comprehensive analysis of inadequate access to water and sanitation services globally and hygiene together with an updated analysis of the burden of disease attributable to water pollution and inadequate sanitation. The Commission is also examining the evidence on the effectiveness of various interventions to improve WASH related health outcomes. The ultimate benefits of upgraded WASH are clear but it can be a challenge to link specific interventions to local health improvements.[63] It is intended that this Commission will provide an authoritative and consistent presentation of the current health burden and the potential benefits of practical interventions.

Progress on Chemicals and Metals Pollution

The Global Burden of Disease study estimates the burden of disease and premature death attributable to a small number of chemicals for which there is strong or probable evidence of health effects. The chemicals included in the GBD analysis include lead, asbestos and a series of occupational carcinogens. The 2019 Global Chemicals Outlook II likewise identifies a small number of chemicals and groups of chemicals where evidence indicates definite or probable risks of disease and death: arsenic; bisphenol A; cadmium; glyphosate; lead; microplastics; neonicotinoids; organotins; phthalates; PAHs and triclosan.[64] Beyond these few chemicals with well-characterized and quantified risks to health, there are thousands of additional chemicals in circulation worldwide. The burden of disease and death attributable to this large and growing number of manufactured chemicals is not known and almost certainly undercounted.

A key barrier to estimating the burden of disease attributable to chemicals is that for most of the thousands of manufactured chemicals now in commerce there are no reliable data on their safety or toxicity. Information is especially lacking on developmental toxicity, reproductive toxicity, the effects of long-term low-level exposures, and the health risks of chemical mixtures. Despite significant progress in the international arena since the 1990s to establish multilateral agreements regulating chemicals in waste, these advances are not enough. Indeed, a 2020 UNEP assessment of issues of concern related to the health and environmental impacts of chemicals and hazardous wastes concluded that "the global goal of sound chemicals and waste management in ways that lead to minimized adverse effects on human health and the environment has not been achieved by 2020."[65]

Inadequate chemical safety testing is a fundamental problem and results in large data gaps in knowledge of toxic effects.[66] The EU, the USA and a few other high-income countries are supporting considerable research efforts to fill these data gaps through the development of new approaches to chemical safety testing. These 'new approach methodologies' overcome two major hurdles in current testing methodologies: costs and time.[67] However, these new approaches rely on high-throughput screens of non-vertebrate animal models, generate large data sets, are computationally and technologically intensive, and have high front-end costs that will make them difficult to transfer to low-income and middle-income countries. Fortunately, however, knowledge of chemical toxicity produced in high-income countries can be exported to low-income and middle-income countries to support decisions on chemical management.

In Europe, the REACH regulations adopted by the EU in 2006 (Registration, Evaluation, Authorisation and Restriction of Chemicals) have established the goal of reducing the risks posed by chemicals to health and the environment. The approach is innovative in that manufacturers or importers are responsible for demonstrating how a chemical can be safely used and must communicate risk managements measures to users and regulators before a chemical can enter markets. This is a full reversal of the previous regulatory system, which presumed chemicals to be harmless until they were proven hazardous and allowed chemicals to remain on the market until a regulator proved that they posed unacceptable risks. Further regulations have followed from REACH and the aim of a "toxic-free environment" has been adopted by the EU.

Progress in documenting the characteristics of all the main chemicals in commerce is proceeding in the EU, although slowly: only a small fraction of the 100,000 chemical compounds on the European market have been tested fully (although priority has been given to those used in the largest volumes). A shortcoming is that information collected under REACH is not completely disclosed, which can complicate access to information by affected countries and sectors and limit efforts to regulate across diverse regions. To date only 62 substances have been banned under REACH,[68] a number that while modest far exceeds the five chemicals that have been banned since 1976 in the USA under the Toxic Substances Control Act.

The European Commission has proposed a new "Chemicals Strategy for Sustainability" to move forward the EU vision of an industry that is "globally competitive in the production and use of safe and sustainable chemicals."[69] This strategy promotes a safe and "sustainable-by-design" approach and a stronger framework to addressing pressing environmental and health concerns. It is based on the understanding that as a Union of rich Member States, the EU cannot afford a race to the bottom with the rapidly expanding chemicals industries in lower-cost countries but must instead initiate a race to the top by minimizing pollution and expanding the scope for chemicals to be re-used and recycled as part of a circular economy. Annexes to the new chemical strategy aim to build global capacity by 2024 to: (1) assess and manage chemicals in Low-income and middle-income countries, (2) ensure that industries do not produce for export chemicals banned in the EU, and (3) promote sustainable production, use, and corporate governance of chemicals.[70]

One of the most concerning aspects of chemical pollution is the failure of governments to implement long-standing commitments to basic measures that would reduce health and environmental risks. In 1992, there was a commitment made at the Rio Earth Summit to devise a Globally Harmonized System for the classification and labelling of hazardous substances, notably chemicals, that would be understandable by illiterate non-specialists and thereby provide valuable protection for the most vulnerable in society. The 2002 follow-up UN Summit in Johannesburg pledged that the GHS system should be implemented everywhere by 2008. However, UNEP's Second Global Chemicals Outlook found that in 2018 no implementation had occurred in 120 countries including all of Africa except Zambia, all of West Asia, all of South Asia and about half of Latin America.[64] Achieving the goal of a global chemical policy should be achievable with a moderate amount of financial support for capacity building.

Other promises on chemical safety that remain off-track and behind schedule include the commitment made under the Stockholm Convention on Persistent Organic Pollutants (POPs) to remove from use by 2025 all equipment containing polychlorinated biphenyls (PCBs). These chemicals, found in electrical transformers and other electrical equipment, are poisonous to people and wildlife. A document prepared for the Conference of the Parties of the Stockholm Convention in 2019 showed that only about 30 percent of Parties had supplied the obligatory reports on their progress in removing PCBs from use.[71]

Of those Parties, about 70 percent expected to eliminate PCBs by the 2025 deadline, although the share fell to 39 percent of responding countries in Africa. It seems likely that those member states that did not fulfil their national reporting obligations or participate in an additional survey are less likely to reach the goal; thus in the worst case scenario where all non-responders fail to meet their goals, only about 40 of the 182 Stockholm Parties might fulfil their 2025 obligation.

Arsenic, hexavalent chromium, and asbestos are likewise amongst the WHO's top 10 chemicals of global public health concern. Long-term arsenic exposure is linked to a wide range of health problems including cancers, cardiovascular, and kidney problems. Early childhood exposure to arsenic can also affect cognitive development.[72] Arsenic exposures, particularly in drinking water from industrial and natural sources, remain problematic in several low- and middle-income countries in south, southeast, and east Asia, most notably Bangladesh, India and China.[73,74] Hotspots in Latin America also exist.[75] Mining is another global source of arsenic pollution.[76,77] Food crops such as rice can be contaminated via groundwater or wastewater and are likewise potential sources of arsenic exposure.[78] Hexavalent chromium, often associated with the tannery industry, is also used as a pigment and elsewhere in industry where it can contaminate groundwater as well as create occupational risks.[79] Hexavalent chromium is genotoxic and a human carcinogen.[80] Asbestos, heavily regulated in high-income countries, is still used widely as a building material in low and middle-income countries, with the most common use as a roofing material (asbestos cement sheets) and water/wastewater plumbing.[81] Asbestos also continues to be mined in several countries including Brazil, China, Kazakhstan, and Russia.[82] Due to its use in the construction industry, laborers are at particular risk for asbestos-related disease including mesothelioma.[83,84] Russia is the world's largest asbestos producer and aggressively markets the mineral to low-income and middle-income countries, sometimes demanding the purchase of Russian asbestos as a precursor to entering into trade negotiations.[85] While asbestos related diseases are peaking in most industrialized countries, they are projected to increase in many LMICs over the next decades.[85] A global ban of asbestos is urgently needed.

More recent chemicals of concern include the perfluorinated compounds - PFOS and PFOA - widely used as water and stain repellents in clothing, household products, food containers, furniture, and carpets, and paints. These compounds are also used extensively in firefighting foams. Sources of human exposure include food, drinking water, dust, and air are all sources of human exposure. Litigation surrounding exposures in to PFOA in West Virginia USA have resulted in large awards.[86] Reviews of toxicity at the low concentrations typical of environmental exposures are in the early stages and indicate likely carcinogenic, immune, metabolic, neurodevelopmental, and reproductive risks.[87]

E-waste recycling is an important and growing source of chemical pollution, particularly in China and Ghana.[88] In 2019, 53·6 million tons of e-waste were generated worldwide, equivalent to 7·3 kg per person.[89] Due to higher consumption rates, shorter life cycles and fewer repair options, by 2030 74·7 million tons of e-waste will be produced worldwide.[89] E-waste is transported in large quantities to LMICs, where it is inadequately recycled, leading to exposures to toxicants including arsenic, cadmium, chromium, dioxin-line compounds, lead, mercury, polychlorinated biphenyls (PCBs) and flame retardants.[90,91] Exposure to these compounds from unsafe e-waste recycling has been associated with severe health impacts, including adverse birth outcomes, altered neurodevelopment, cancer, and respiratory and cardiovascular disease.[89]

Increased demand for electric vehicles has also lead to rising demand for metals used in battery production, notably the rare earth oxides lithium and cobalt.[92] Cobalt is known to have adverse effects on human neurological, cardiovascular, and endocrine systems.[93] The Katanga Copperbelt in DR Congo supplies the world with 60 percent of the global cobalt supply, with 15-20 percent delivered by artisanal miners.[94] Congolese artisanal miners and individuals living in and around mining communities have shown increased cobalt levels in blood and urine.[94]

Progress on Lead Pollution

Recent data from IHME finds that one in three children globally suffer blood lead levels above the US CDC reference level of 5 µg/dl.[95] Although the implications for society and economies of this finding are substantial, attention to lead poisoning in most LMICs, where most lead poisoning occurs, is minimal.

Mexico recently added lead testing to its periodic health survey.[96] Elevated lead exposures have been long been highly prevalent in Mexico. In addition to traditional sources of exposure (mining and occupational), the key source of lead exposure is deeply embedded in Mexican culture: the use of lead-glazed ceramics to cook, store and serve food. The production process and the widespread use of lead in pottery in Mexico suggest that the prevalence of lead poisoning (LP: ≥5 µg/dL) should be high, but until recently there was no accurate estimate. In 2015 the first state-representative survey of blood lead levels in newborn infants was conducted in Morelos State. The prevalence of lead poisoning was found to be 14·7 percent (CI 95%: 11·1, 19·3) and in the most marginalized regions of the State reached 22·2 percent (CI 95%: 14·4, 32·5).[97] These results led the government to scale up the study to a national level through the National Survey of Health and Nutrition (ENSaNut). This is a household survey and represents a key new instrument in the design of health policy in Mexico. In 2018-19, the state-representative health survey ENSaNut included blood lead measurements (BLM) in 1-4-year-old children. The estimated national prevalence of LP was 17·4 percent (CI 95% 14·8, 20·0) representing 1.4 million children, with wide variation among states. While Puebla state, with a long tradition of use of lead-glazed ceramics, recorded a prevalence of 46·6 percent (CI95%: 30·7, 63·3), followed by San Luis Potosí (37·4 percent) and Tlaxcala States (35·6 percent), other states had zero or near-zero prevalence: Sinaloa (0 percent) and Tabasco (0·8 percent). These results were treated as a public health emergency and triggered the implementation of a national comprehensive plan to reduce population lead exposures derived from the use of lead-glazed ceramics. Strategies include lowering the blood-reference level, efforts to reduce and eventually eliminate the use of lead in ceramic production, social awareness strategies, and a hybrid individual and population-level blood-lead biomonitoring surveillance system to encompass susceptible sub-populations and the general population.

China has also made efforts to determine baseline exposures to lead.[98,99] From the late 1990s through 2009, average blood lead levels in urban Chinese children 0-6 years of age decreased from 7-10 µg/dL to 2·5-6 µg/dL. The prevalence of children with higher blood lead levels (>10µg/dL) also decreased substantially, from 30–50 percent to 1·5–15 percent. This decline in blood lead levels appears to have been associated with national efforts to decrease lead pollution, including the phase-out of leaded gasoline, a transition from coal fuel to diesel, natural gas, and clean energy alternatives, and closing or merging heavily polluting enterprises.[100] However, a recent review of 219 published articles found that blood lead levels in Chinese children remain high, with over 8 percent of 629,627 children showing blood lead levels higher than 10 µg/dL.[101] Based on these findings, efforts are underway to modify guidelines for childhood lead poisoning prevention in China.

Most low- and middle-income countries do not have blood lead or environmental lead monitoring systems in place.[102] Targeted, data-driven prevention of childhood lead poisoning is thus not possible except in the most obvious exposure circumstances. The international response to the problem of childhood lead exposure in low-income and middle-income countries has focused mainly on lead in paint.[103]

Progress on Mercury Pollution

Mercury is a highly toxic metal and its toxicity includes neurodevelopmental, neurotoxic, cardiovascular, reproductive and immunological effects.[104—107] Mercury exposure levels vary by population. The highest exposures occur at the source of emission amongst populations who come into regular contact with mercury occupationally, and amongst Arctic, small island, tropical riverine and coastal communities who have a high intake of fish and seafood contaminated with methyl-mercury, which, as a diffuse pollutant, migrates with air and water and bio-magnifies after penetrating the food chain.[108,109] In 2015, artisanal and small-scale gold mining activities (ASGM) were found to be responsible for 38 percent of global anthropogenic mercury emissions, followed by coal combustion (21 percent), non-ferrous metal production (15 percent) and cement production (11 percent).[110,111] ASGM is a main source of mercury release into aquatic systems, followed by disposal of mercury-containing products, domestic wastewater, metal production, and releases from industry.[112,113] New studies under the Minamata Convention are underway to better understand the contributions of oil and gas mining to the incidence of mercury to the environment.

The Minamata Convention calls for international and national action on mercury to protect health and the environment and includes a financing mechanism for the implementation of the Convention.[110] Agreed upon in 2013, it entered into force in 2017 and has been ratified by 130 countries. The Convention includes a non-punitive compliance mechanism that helps countries to fulfil their obligations. The main funding tool is the Global Environment Facility (GEF), especially via its Chemicals and Wastes and "Planet Gold" program. The World Bank supports several projects to control pollution, for example its "Pollution Management and Environmental Health" program. UN Environment Program also hosts the "Global Mercury Partnership", which aims to protect human health and the global environment from the release of mercury and works closely with stakeholders to assist in the timely ratification and effective implementation of Convention objectives.

The great strengths of the Minamata Convention are its clear agenda, with health as a priority issue (§ 1 and § 16), its globally binding construction, and the inclusion of a sustainable funding mechanism through GEF. However, like other UN treaties, decision-making under the Convention depends on the consensus of their partners, causing delays and curbing ambition and new approaches. Interventions are also typically implemented as time-limited projects rather than as sustainable, comprehensive, long-time interventions.[114] Intervention efforts are also limited by lack of data on sources and long-term biomonitoring, particularly in low- and middle-income countries.[115]

Phasing out mercury demands strong collaborative efforts among scientists, policymakers, and mercury users. To change attitudes and behaviours, knowledge transfer, microfinance, legalisation, and especially, participation of those ASG miners who are at the end of the value chain are needed above all.[116,117] It is vital to recognise that those individuals and corporations who profit most from extractive activities such as mining are in industrialized countries and that they consistently outsource the health and environmental risks of mercury extraction and use to low-income and middle-income countries.

While in recent years, great strides have been made by both scientists and policy makers to reduce mercury emissions and human exposure, intensified collaboration across sectors, exchange of knowledge, training and awareness raising, and participation of the affected parties is needed to improve further urgently needed actions to minimize the persistent health hazards from global mercury pollution.

Progress on Asbestos Pollution

The asbestos minerals – actinolite, amosite, anthophyllite, chrysotile crocidolite, and tremolite – are a group of naturally occurring fibrous silicates. Asbestos can withstand fire, heat, and acid. It has great tensile strength. It provides thermal and acoustic insulation. For these reasons, asbestos came into use in the 19th century, was heavily used through much of the 20th century, mainly in insulation and construction materials, and is still used today. Chrysotile, 'white asbestos', accounts for 95 percent of all asbestos ever used and is the only form in use today.[118]

All forms of asbestos are now recognized to cause asbestosis, a progressive, fibrotic lung disease. All forms of asbestos also cause multiple cancers including malignant mesothelioma, lung cancer, laryngeal cancer, ovarian cancer, and possibly gastrointestinal cancers.[119] Asbestos has been declared a proven human carcinogen by the International Agency for Research on Cancer and by national regulatory bodies in many countries. There is no safe level of exposure.

The health hazards of asbestos were first recognized in the early 20th century with the diagnosis of asbestosis among asbestos-exposed workers. The first reports of cancer in workers exposed to asbestos were published in the UK and the USA in the mid-1930s. A landmark 1964 publication by Irving Selikoff confirmed the association between asbestos and cancer and had major impacts on regulatory policy.[120] In the years following publication of this report, asbestos consumption in the USA fell by more than 99 percent. Similar declines took place over the following two decades in most other high-income countries as well as in many low-income and middle-income countries, and asbestos is now banned in 44 countries, including all EU member states. After lag periods of 10-20 years (reflecting the long latency of asbestos-related cancers), substantial reductions in asbestos-related mortality have resulted in these countries.[121]

Despite wide knowledge of asbestos' dangers, many countries still use, import, and export asbestos, and annual world production remains at about 2 million tons. Russia is by far the leading producer nation, followed by China, Kazakhstan, Brazil, Zimbabwe, and Colombia.[118] China is the largest consumer, followed by India, Russia, Kazakhstan, Thailand, Ukraine, and Uzbekistan. The 2019 Global Burden of Disease study attributes over 230,000 global deaths to asbestos, a number that almost certainly is an undercount of the true burden.[122] In low-income and middle-income countries, where too often there exists little or no protection of workers and communities, asbestos may be expected to cause epidemics of lung cancer, mesothelioma, and other malignancies that will extend over much of this century.[121]

Repeated efforts to control international trade in asbestos under the Rotterdam Convention have failed, because of the Convention's requirement for unanimity among all Parties to the Convention, a legality that has enabled a few asbestos-producing nations to block the desire of more than 100 other countries to end the asbestos trade.[121] Russia aggressively markets asbestos to low-income and middle-income countries, sometimes demanding the purchase of Russian asbestos as a precursor to entering into trade negotiations.

References

[1] PlumX Metrics: The Lancet Commission on Pollution and Health. Available at: https://plu.mx/plum/a/?doi=10.1016/S0140-6736(17)32345-0&theme=plum-jbs-theme&hideUsage=true. Accessed 21 February 2022.
[2] Sulaymon ID. PM2.5 in Abuja, Nigeria: Chemical characterization, source apportionment, temporal variations, transport pathways and the health risks assessment. Atmospheric Research. 2020;237:104833.
[3] Tefera W. Chemical Characterization and Seasonality of Ambient Particles (PM2. 5) in the City Centre of Addis Ababa. Int J Environ Res Public Health. 2020;17(19):6998.
[4] Health Effects Institute and Institute for Health Metrics and Evaluation. State of Global Air 2020: A Special Report on Global Air Exposure and its Health Impacts. Boston: Health Effects Institute. Available at: https://www.stateofglobalair.org/. Accessed 17 July 2020
[5] India State-Level Disease Burden Initiative Air Pollution Collaborators. Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. Lancet Planet Health. 2021;5(1):e25–38.
[6] Ganguly T, Selvaraj KL, Guttikunda SK. National Clean Air Programme (NCAP) for Indian cities: Review and outlook of clean air action plans. Atmospheric Environment 2020 8(100096):100096.
[7] Ganguly, T., Kurinji, L. S., & Guttikunda, S. How Robust are Urban India's Clean Air Plans? An Assessment of 102 Cities. New Delhi, Council on Energy, Environment and Water, 2020. Available at: https://www.ceew.in/publications/how-robust-are-urban-india%E2%80%99s-clean-air-plans. Accessed 5 May 2021.
[8] Natural Resources Defense Council and Public Health Foundation India. Clearing the Air: Highlighting Actions to Reduce Air Pollution in India. New York: National Resources Defence Council, 2019. Available at: https://www.nrdc.org/sites/default/files/clearing-air-reduce-air-pollution-india-fs.pdf. Accessed November 12, 2020.
[9] Environmental Pollution Prevention and Control Authority. Delhi & NCR: Air Pollution Report Card 2017-18. Environmental Pollution Prevention and Control Authority: Centre for Science and Environment, 2018. Available at: http://www.indiaenvironmentportal.org.in/content/452297/delhi-ncr-air-pollution-report-card- 2017-18/#:~:text=Delhi%20and%20its%20surrounding%20region's,Control)%20Authority%20(EPCA). Accessed November 12, 2020.
[10] Zhang J, Jiang H, Zhang W, Ma G, Wang Y, Lu Y, et al. Cost-benefit analysis of China's action plan for air pollution prevention and control. Front Eng Manag. 2019;6(4):524–37.
[11] Clean Air Asia. China Air 2020 - Air Pollution Prevention and Control Progress in Chinese Cities. Beijing: Clean Air Asia, 2020. Available at: https://cleanairasia.org/china-air-2020/. Accessed 13 April 2021. Accessed November 12, 2020.
[12] Greenstone, M., & Schwarz, P. Is China Winning its War on Pollution? Air Quality Life Index, 2018. Available at: https://aqli.epic.uchicago.edu/wp-content/uploads/2018/08/AQLI-UChicago-Report-Is-China-Winning-its- War-on-Pollution.pdf. Accessed November 12 2020.

[13] Yin P, Brauer M, Cohen AJ, Wang H, Li J, Burnett RT, et al. The effect of air pollution on deaths, disease burden, and life expectancy across China and its provinces, 1990-2017: an analysis for the Global Burden of Disease Study 2017. Lancet Planet Health. 2020;4(9): e386–98.
[14] World Bank. Clearing the Air: A Tale of 3 Cities. New York: World Bank, 2020. Available at: https://openknowledge.worldbank.org/handle/10986/34757. Accessed November 16, 2020.
[15] Government of Mexico. Mexican Norm 172. Mexico City: Government of Mexico, 2019. Available at : https://dof.gob.mx/nota_detalle.php?codigo=5579387&fecha=20/11/2019. Accessed 3 February 2021.
[16] Onakpohor A, Fakinle BS, Sonibare JA, Oke MA, Akeredolu FA. Investigation of air emissions from artisanal petroleum refineries in the Niger-Delta Nigeria. Heliyon. 2020;6(11):e05608.
[17] Croitoru L, Akpokodje J, Chang JC, Kelly A. The cost of air pollution in Lagos. Lagos: World Bank, 2020. Available at: https://www.worldbank.org/en/topic/environment/publication/the-cost-of-air-pollution-in- lagos. Accessed January 21 2021.
[18] Organization for Economic Cooperation and Development. Urbanisation Dynamics in West Africa 1950–2010. Paris: OECD, 2015. Available at: https://doi.org/10.1787/2074353x. Accessed October 20 2020.
[19] Mbow-Diokhane A. Air Quality in African Cities. Smart Economy in Smart African Cities: Sustainable, Inclusive, Resilient and Prosperous. Mboup G, Oyelaran-Oyeyinka B, editors. Singapore, Springer Singapore; 2019. p.297–311.
[20] UNICEF. Silent suffocation in Africa: Air pollution is a growing menace. New York: UNICEF, 2019. Available at: https://www.unicef.org/reports/silent-suffocation-in-africa-air-pollution-2019. Accessed October 20 2020.
[21] Makoni M. Air pollution in Africa. The Lancet Respiratory Medicine. 2020;8(7):60– 61. 175.Singh A, Avis WR, Pope FD. Visibility as a proxy for air quality in East Africa. Environ Res Lett.2020;15(8):084002.
[22] Pope FD, Gatari M, Ng'ang'a D, Poynter A, Blake R. Airborne particulate matter monitoring in Kenya using calibrated low-cost sensors. Atmos Chem Phys. 2018;18(20):15403–18.
[23] Air Quality and Mobility. Sulphur level in diesel globally. Nairobi, Air Quality and Mobility, 2020. Available at: http://www.airqualityandmobility.org/gfeitoolkit/sulphur.html. Accessed 20 October 2020.
[24] UN Environment Program. West African ministers adopt cleaner fuels and vehicles standards. Nairobi: UNEP, 2020. Available at : https://www.unenvironment.org/news-and-stories/story/west-african-ministers-adopt- cleaner-fuels-and-vehicles-standards. Accessed 20 October 2020.
[25] Jeremiah, K., Olayinka, C., Ebiri, K., and Muanya, C. Nigeria gets 2021 deadline to stop dirty fuel imports. The Guardian, 6 July 2020. Available at: https://guardian.ng/news/nigeria-gets-2021-deadline-to-stop-dirty-fuel- imports
[26] UN Environment Program. Used vehicles and the environment. A global overview of used light duty vehicles: Flow, scale and regulation. Geneva: UNEP, 2020. Available at: https://www.unep.org/resources/report/global-trade-used-vehicles-report. Accessed 8 February 2021.
[27] US Environmental Protection Agency. Nitrogen Dioxide (NO2) Pollution. Washington DC: US EPA, 2016. Available at : https://www.epa.gov/no2-pollution/basic-information-about-no2#Effects. Accessed 9 April 2021.
[28] Hickman JE, Andela N, Tsigaridis K, Galy-Lacaux C, Ossohou M, Bauer SE. Reductions in NO2 burden over north equatorial Africa from decline in biomass burning in spite of growing fossil fuel use, 2005 to 2017. Proc Natl Acad Sci U S A. 2021;118(7):e2002579118.
[29] Global Alliance on Health and Pollution, Boston College, and Air Quality Asia. Air Pollution Interventions: Climate and Health Impacts. Geneva: GAHP, 2020. Available at: https://gahp.net/report-

air-pollution- interventions-seeking-the-intersection-between-climate-health. Accessed 12 November 2020.
[30] Pinder RW, Klopp JM, Kleiman G, Hagler GSW, Awe Y, Terry S. Opportunities and challenges for filling the air quality data gap in low- and middle-income countries. Atmos Environ 2019;215(116794):116794.
[31] Martin RV, Brauer M, van Donkelaar A, Shaddick G, Narain U, Dey S. No one knows which city has the highest concentration of fine particulate matter. Atmospheric Environment 2019;3(100040):100040
[32] UN Environment Program. Air Pollution in Asia and the Pacific: Science-based Solutions. Bangkok: UNEP, 2018. Available at: https://wedocs.unep.org/handle/20.500.11822/26861. Accessed 15 November 2020.
[33] World Health Organisation. Exposure to Household Air Pollution for 2016. Geneva: WHO, 2018. Available at: www.who.int/airpollution/data/HAP_exposure_results_final.pdf. Accessed January 5 2021.
[34] International Energy Agency. SDG7: Data and projections. Paris: International Energy Agency, 2019. Available at: https://www.iea.org/reports/sdg7-data-and-projections. Accessed 11 January 2021.
[35] Ritchie, H. & Roser, M. Indoor Air Pollution. Our World in Data, 2019. https://ourworldindata.org/indoor-air- pollution. Accessed August 18 2020.
[36] Zhao B, Zheng H, Wang S, Smith KR, Lu X, Aunan K, et al. Change in household fuels dominates the decrease in PM2.5 exposure and premature mortality in China in 2005-2015. Proc Natl Acad Sci U S A.2018;115(49):12401–6.
[37] Shen G, Ru M, Du W, Zhu X, Zhong Q, Chen Y, et al. Impacts of air pollutants from rural Chinese households under the rapid residential energy transition. Nat Commun. 2019;10(1):3405.
[38] Balakrishnan K, Cohen A, Smith KR. Addressing the burden of disease attributable to air pollution in India: the need to integrate across household and ambient air pollution exposures. Environ Health Perspect. 2014;122(1):6-7.
[39] Mani S, Jain A, Tripathi S, Gould CF. The drivers of sustained use of liquified petroleum gas in India. Nat Energy. 2020;5(6):450–7.
[40] Chowdhury, S., Chafe, Z.A., Pillarisetti, A., Lelieveld, J., Guttikunda, S. and Dey, S. The Contribution of Household Fuels to Ambient Air Pollution in India: A Comparison of Recent Estimates. Collaborative Clean Air Policy Centre, Policy Brief (CCAPC/2019/01) New Delhi, 2019. Available at: https://web.iitd.ac.in/~sagnik/CCAPC2019.pdf. Accessed 12 June 2020.
[41] UN Environment Program. Review of Woodfuel Biomass Production and Utilization in Africa: A Desk Study. Nairobi, Kenya: UNEP, 2019. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/28515/WoodfuelRpt.pdf?sequence=1&isAllowed=y. Accessed 12 June 2020.
[42] International Energy Agency et al. Tracking SDG7: The Energy Progress Report: Ethiopia. Paris: IEA, 2020. Available at: https://trackingsdg7.esmap.org/country/Ethiopia. Accessed January 5 2021.
[43] Thomas E, Wickramasinghe K, Mendis S, Roberts N, Foster C. Improved stove interventions to reduce household air pollution in low and middle income countries: a descriptive systematic review. BMC Public Health. 2015;15(1):650
[44] Shupler M, Hystad P, Gustafson P, Rangarajan S, Mushtaha M, Jayachtria KG, et al. Household, community, sub-national and country-level predictors of primary cooking fuel switching in nine countries from the PURE study. Environ Res Lett. 2019;14(8):085006.
[45] Pinto, AN, Wang, Y., Ochieng, CA, Wu, J., George, P., Zhang, Y., Alexander, D., Batchelor, S., Brown, E. and Durix, L. The State of Access to Modern Energy Cooking Services. MECS/ESMAP/World Bank Group

Executive Summary. New York: World Bank, 2020. Available at: https://mecs.org.uk/download-category/report/. Accessed 3 September 2020.
[46] Climate and Clean Air Coalition. 2030 Vision Statement. Climate and Clean Air Coalition. Paris: Climate and Clean Air Coalition, 2020. Available at: https://www.ccacoalition.org/en/content/our-2030-vision. Accessed 3 September 2020.
[47] Pozzer A, Tsimpidi AP, Karydis VA, de Meij A, Lelieveld J. Impact of agricultural emission reductions on fine- particulate matter and public health. Atmos Chem Phys. 2017;17(20):12813–26.
[48] World Health Organization. WHO Analysis and Recommendations on Health-Promoting Nationally Determined Contributions (NDCs) to the Paris Agreement. Geneva: WHO, 2019. Available at: https://www.who.int/publications/i/item/who-review-health-in-the-ndcs. Accessed 3 June 2020.
[49] Shindell D, Kuylenstierna JCI, Vignati E, van Dingenen R, Amann M, Klimont Z, et al. Simultaneously mitigating near-term climate change and improving human health and food security. Science. 2012;335(6065):183–9.
[50] International Energy Agency. Renewables 2020: Analysis and forecast to 2025. Paris: International Energy Agency, 2019. Available at: https://www.iea.org/reports/renewables-2020. Accessed 5 January 2021.
[51] International Renewable Energy Agency. Renewable Power Generation Costs in 2019. Abu Dhabi: IREA, 2020.Available at: https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019. Accessed 5 January 2021.
[52] International Energy Agency. Global electric vehicle outlook 2019. Paris: IEA, 2020. Available at: https://www.iea.org/reports/global-ev-outlook-2019. Accessed 5 January 2021.
[53] Ocko IB, Hamburg SP. Climate impacts of hydropower: Enormous differences among facilities and over time. Environ Sci Technol. 2019;53(23):14070–82.
[54] Calder RSD, Schartup AT, Li M, Valberg AP, Balcom PH, Sunderland EM. Future impacts of hydroelectric power development on methylmercury exposures of Canadian indigenous communities. Environ Sci Technol. 2016;50(23):13115–22.
[55] Miller LM, Keith DW. Observation-based solar and wind power capacity factors and power densities. Environ Res Lett. 2018;13(10):104008.
[56] United Nations and World Bank. Making every drop count: An agenda for water action. High-level panel on water outcome document. Geneva: United Nations, 2018. Available at: https://sustainabledevelopment.un.org/content/documents/17825HLPW_Outcome.pdf. Accessed 11 January 2021.
[57] UN Water. Progress on Ambient Water Quality - Piloting the monitoring methodology and initial findings for SDG 6 indicator 6.3.2. New York: UN Water, 2019. Available at: https://www.unwater.org/publications/progress-on-ambient-water-quality-632/. Accessed 11 January 2021.
[58] UNICEF and World Health Organization. Progress on household drinking water, sanitation and hygiene 2000- 2017: Special focus on inequalities. New York: UNICEF, 2019. Available at: https://www.who.int/water_sanitation_health/publications/jmp-report-2019/en/. Accessed 11 January 2021.
[59] UN Water. SDG 6 Synthesis Report 2018 on Water and Sanitation. New York: UN, 2018. Available at: https://www.unwater.org/publications/highlights-sdg-6-synthesis-report-2018-on-water-and-sanitation-2/. Accessed 11 January 2021.

[60] Independent Evaluation Group. A Thirst for Change: The World Bank Group's Support for Water Supply and Sanitation, with Focus on the Poor. Washington, DC: Independent Evaluation Group, 2017. Available at: https://ieg.worldbankgroup.org/evaluations/water-sanitation. Accessed 11 January 2021.
[61] UNICEF & WHO (2020). State of the World's Sanitation: An urgent call to transform sanitation for better health, environments, economies and societies. Available at: https://www.who.int/publications/i/item/9789240014473. Accessed 11 January 2021.
[62] Prüss-Ustün A, Wolf J, Bartram J, Clasen T, Cumming O, Freeman MC, et al. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: An updated analysis with a focus on low- and middle-income countries. Int J Hyg Environ Health. 2019;222(5):765–77.
[63] Cumming O, Arnold BF, Ban R, Clasen T, Esteves Mills J, Freeman MC, et al. The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. BMC Med. 2019;17(1):173.
[64] UN Environment Program. Global Chemicals Outlook II: From Legacies to Innovative Solutions: Implementing the 2030 Agenda for Sustainable Development. Geneva: UNEP, 2019. Available at: https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/policy-and-governance/global-chemicals-outlook
[65] United Nations Environment Program. An Assessment Report on Issues of Concern: Chemicals and Waste Issues Posing Risks to Human Health and the Environment. Geneva: UNEP, 2020. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/33807/ARIC.pdf?sequence=1&isAllowed=y. Accessed 5 January 2021.
[66] Krewski D, Andersen ME, Tyshenko MG, Krishnan K, Hartung T, Boekelheide K, Wambaugh JF, Jones D, Whelan M, Thomas R, Yauk C, Barton-Maclaren T, Cote I. Toxicity testing in the 21st century: progress in the past decade and future perspectives. Arch Toxicol. 2020 Jan;94(1):1-58. doi: 10.1007/s00204-019-02613-4
[67] Parish ST, Aschner M, Casey W, Corvaro M, Embry MR, Fitzpatrick S, et al. An evaluation framework for new approach methodologies (NAMs) for human health safety assessment. Regul Toxicol Pharmacol. 2020;112(104592):104592.
[68] European Commission. Study for the strategy for a non-toxic environment of the 7th Environment Action Programme Final Report. Brussels: European Commission, 2017. Available at: https://ec.europa.eu/environment/chemicals/non-toxic/pdf/NTE%20main%20report%20final.pdf. Accessed 17 February 2021.
[69] European Commission. Chemicals Strategy for Sustainability: Towards a Toxic-Free Environment. Brussels: European Commission, 2020. Available at: https://ec.europa.eu/environment/strategy/chemicals- strategy_en. Accessed 5 January 2021.
[70] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Chemicals Strategy for Sustainability Towards a Toxic-Free Environment. Brussels: European Commission, 2020. Available at: https://ec.europa.eu/environment/pdf/chemicals/2020/10/Annex.pdf. Accessed 14 April 2021.
[71] UN Environment Program. Report of the Conference of the Parties to the Stockholm Convention on Persistent Organic Pollutants on the work of its ninth meeting. Nairobi: UNEP, 2020. Available at: http://chm.pops.int/TheConvention/ConferenceoftheParties/Meetings/COP9/tabid/7521/Default.aspx. Accessed 13 April 2021.

[72] World Health Organization. Arsenic: fact sheet. Geneva: WHO, 2020. Available at: https://www.who.int/en/news-room/fact-sheets/detail/arsenic
[73] Jha PK, Tripathi P. Arsenic and fluoride contamination in groundwater: a review of global scenarios with special reference to India. Ground Sustain Dev. 2021 (100576):100576.
[74] Akhtar E, Roy AK, Haq MA, von Ehrenstein OS, Ahmed S, Vahter M, et al. A longitudinal study of rural Bangladeshi children with long-term arsenic and cadmium exposures and biomarkers of cardiometabolic diseases. Environ Pollut. 2021;271(116333):116333
[75] De Loma J, Gliga AR, Levi M, et al. Arsenic Exposure and Cancer-Related Proteins in Urine of Indigenous Bolivian Women. Front Public Health 2020; 8: 605123.
[76] Li Y, Ji L, Mi W, Xie S, Bi Y. Health risks from groundwater arsenic on residents in northern China coal-rich region. Sci Total Environ. 2021;773(145003):145003.
[77] Tapia J, Murray J, Ormachea M, Tirado N, Nordstrom DK. Origin, distribution, and geochemistry of arsenic in the Altiplano-Puna plateau of Argentina, Bolivia, Chile, and Perú. Sci Total Environ. 2019;678:309–25.
[78] Gibb HJ, Barchowsky A, Bellinger D, Bolger PM, Carrington C, Havelaar AH, et al. Estimates of the 2015 global and regional disease burden from four foodborne metals - arsenic, cadmium, lead and methylmercury. Environ Res. 2019;174:188–94.
[79] Jobby R, Jha P, Yadav AK, Desai N. Biosorption and biotransformation of hexavalent chromium [Cr(VI)]: A comprehensive review. Chemosphere. 2018;207:255–66.
[80] Deng Y, Wang M, Tian T, Lin S, Xu P, Zhou L, et al. The effect of hexavalent chromium on the incidence and mortality of human cancers: A meta-analysis based on published epidemiological cohort studies. Front Oncol. 2019;9:24.
[81] United States Geological Survey. Asbestos. Available at: https://pubs.usgs.gov/periodicals/mcs2020/mcs2020- asbestos.pdf. Accessed 12 March 2021.
[82] Noonan CW. Environmental asbestos exposure and risk of mesothelioma. Ann Transl Med. 2017;5(11):234. 260.Noonan CW. Environmental asbestos exposure and risk of mesothelioma. Ann Transl Med. 2017;5(11):234.
[83] Suraya A, Nowak D, Sulistomo AW, et al. Excess Risk of Lung Cancer Among Agriculture and Construction Workers in Indonesia. Ann Glob Health 2021; 87(1): 8.
[84] Collegium Ramazzini. The global health dimensions of asbestos and asbestos-related diseases. Ann Glob Health. 2016;82(1):209–13.
[85] Frank A, Joshi TK. The global spread of asbestos. Ann Glob Health. 2014;80(4):257. 264.Frank A, Joshi TK. The global spread of asbestos. Ann Glob Health. 2014;80(4):257.
[86] New York Times Magazine. The lawyer who became Dupont's worst nightmare. New York, 16 January 2016.Available at: https://www.nytimes.com/2016/01/10/magazine/the-lawyer-who-became-duponts-worst- nightmare.html
[87] Sunderland EM, Hu XC, Dassuncao C, Tokranov AK, Wagner CC, Allen JG. A review of the pathways of human exposure to poly- and perfluoroalkyl substances (PFASs) and present understanding of health effects. J Expo Sci Environ Epidemiol. 2019;29(2):131–47.
[88] Heacock M, Kelly CB, Asante KA, Birnbaum LS, Bergman ÅL, Bruné M-N, et al. E-waste and harm to vulnerable populations: A growing global problem. Environ Health Perspect. 2015;124(5). http://dx.doi.org/10.1289/ehp.1509699
[89] Forti V., Baldé C.P., Kuehr R., Bel G. The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential. United Nations University (UNU)/United Nations Institute for Training and

Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam
[90] Li W, Achal V. Environmental and health impacts due to e-waste disposal in China - A review. Sci Total Environ. 2020;737(139745):139745.
[91] Kyere VN, Greve K, Atiemo SM, Amoako D, Aboh IJK, Cheabu BS. Contamination and health risk assessment of exposure to heavy metals in soils from informal E-waste recycling site in Ghana. Emerg Sci J. 2018;2(6):428.
[92] Alves Dias P., Blagoeva D., Pavel C., Arvanitidis N., Cobalt: demand-supply balances in the transition to electric mobility, EUR 29381 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79- 94311-9, doi:10.2760/97710, JRC112285.
[93] Leyssens L, Vinck B, Van Der Straeten C, Wuyts F, Maes L. Cobalt toxicity in humans—A review of the potential sources and systemic health effects. Toxicology. 2017;387:43–56.
[94] Banza Lubaba Nkulu C, Casas L, Haufroid V, De Putter T, Saenen ND, Kayembe-Kitenge T, et al. Sustainability of artisanal mining of cobalt in DR Congo. Nat Sustain. 2018;1(9):495–504.
[95] UNICEF and Pure Earth. The Toxic Truth: Children's exposure to lead pollution undermines a generation of future potential. New York: UNICEF & Pure Earth, 2020. Available at: https://www.unicef.org/reports/toxic- truth-childrens-exposure-to-lead-pollution-2020
[96] Téllez-Rojo MM, Bautista-Arredondo LF, Trejo-Valdivia B, Cantoral A, Estrada-Sánchez D, Kraiem R, et al. Reporte nacional de niveles de plomo en sangre y uso de barro vidriado en población infantil vulnerable. Salud Publica Mex. 2019;61(6):787–97.
[97] Téllez-Rojo MM, Bautista-Arredondo LF, Richardson V, Estrada-Sánchez D, Ávila-Jiménez L, Ríos C, et al. Intoxicación por plomo y nivel de marginación en recién nacidos de Morelos, México. Salud Publica Mex. 2017;59(3, may-jun):218.
[98] Li T, Zhang S, Tan Z, Dai Y. Trend of childhood blood lead levels in cities of China in recent 10 years. Environ Sci Pollut Res Int. 2017;24(6):5824–30.
[99] Zhang Y, O'Connor D, Xu W, Hou D. Blood lead levels among Chinese children: The shifting influence of industry, traffic, and e-waste over three decades. Environ Int. 2020;135(105379):105379.
[100] Yan C-H, Xu J, Shen X-M. Childhood lead poisoning in China: challenges and opportunities. Environ Health Perspect. 2013;121(10):A294.
[101] Liu Y, Liu F, Dong KF, Wu Y, Yang X, Yang J, et al. Regional characteristics of children's blood lead levels in China: A systematic synthesis of national and subnational population data. Sci Total Environ. 2021;769(144649):144649.
[102] Kordas K, Ravenscroft J, Cao Y, McLean EV. Lead exposure in low and middle-income countries: Perspectives and lessons on patterns, injustices, economics, and politics. Int J Environ Res Public Health. 2018;15(11):2351.
[103] UN Environment Program. Global Alliance to Eliminate Lead in Paint. Geneva: UNEP, 2019. Available at: https://www.unenvironment.org/explore-topics/chemicals-waste/what-we-do/emerging-issues/global- alliance-eliminate-lead-paint#:~:text=The%20Global%20Alliance%20to%20Eliminate,out%20of%20paints%20containing%20lead
[104] World Health Organization. Mercury and Health - key facts. Geneva: WHO, 2021. Available at: https://www.who.int/news-room/fact-sheets/detail/mercury-and-health. Accessed 8th of February 2021

[105] Reuben A, Frischtak H, Berky A, Ortiz EJ, Morales AM, Hsu-Kim H, et al. Elevated hair mercury levels are associated with neurodevelopmental deficits in children living near artisanal and small-scale gold mining in Peru. GeoHealth. 2020;4(5):e2019GH000222.
[106] Ha E, Basu N, Bose-O'Reilly S, Dórea JG, McSorley E, Sakamoto M, et al. Current progress on understanding the impact of mercury on human health. Environ Res. 2017;152:419–33.
[107] Julvez J, Davey Smith G, Ring S, Grandjean P. A birth cohort study on the genetic modification of the association of prenatal methylmercury with child cognitive development. Am J Epidemiol.2019;188(10):1784–93.
[108] Basu N, Horvat M, Evers DC, Zastenskaya I, Weihe P, Tempowski J. A state-of-the-science review of mercury biomarkers in human populations worldwide between 2000 and 2018. Environ Health Perspect. 2018;126(10):106001.
[109] Basu N. The Minamata Convention on Mercury and the role for the environmental sciences community. Environ Toxicol Chem. 2018;37(12):2951–2.
[110] UN Environment Programme. (2020) Progress Report 2020 - Overview of the Minamata Convention on Mercury acitivities, Available at:https://mercuryconvention.org/Portals/11/documents/Minamata-Progress- report-2020.pdf. Accessed 8 February 2021
[111] UN Environment Program (2019). Global Mercury Assessment 2018. Geneva, Switzerland: UN Environment Programme, Chemicals and Health Branch.
[112] Kocman D, Wilson S, Amos H, Telmer K, Steenhuisen F, Sunderland E, et al. Toward an assessment of the global inventory of present-day mercury releases to freshwater environments. Int J Environ Res Public Health. 2017;14(2):138.
[113] Obrist D, Kirk JL, Zhang L, Sunderland EM, Jiskra M, Selin NE. A review of global environmental mercury processes in response to human and natural perturbations: Changes of emissions, climate, and land use. Ambio. 2018;47(2):116–40.
[114] Veiga MM, Fadina O. A review of the failed attempts to curb mercury use at artisanal gold mines and a proposed solution. Extr Ind Soc. 2020;7(3):1135–46.
[115] Xu Z, Lu Q, Xu X, Feng X, Liang L, Liu L, et al. Multi-pathway mercury health risk assessment, categorization and prioritization in an abandoned mercury mining area: A pilot study for implementation of the Minamata Convention. Chemosphere. 2020;260(127582):127582.
[116] Ottenbros I, Boerleider R, Jubitana B, Roeleveld N, Scheepers PT. Knowledge and awareness of health effects related to the use of mercury in small-scale artisanal gold mining in Suriname. Environ Health Perspect 2018 (1). http://dx.doi.org/10.1289/isesisee.2018.p01.1790
[117] Becker J, Furu P, Singo J, et al. Determinants of health and health needs assessment of artisanal and small- scale gold miners in Kadoma, Zimbabwe: A mixed method approach. Environmental Research. 2021 Mar;197:111081. DOI: 10.1016/j.envres.2021.111081.
[118] Frank A, Joshi TK. The global spread of asbestos. Ann Glob Health. 2014;80(4):257.
[119] Straif K, Benbrahim-Tallaa L, Baan R, et al. A review of human carcinogens — Part C: metals, arsenic, dusts, and fibres. Lancet Oncol 2009; 10: 453-4.
[120] Selikoff IJ, Churg J, Hammond EC. Asbestos exposure and neoplasia. JAMA 1964; 188: 22–26
[121] Takahashi K, Landrigan PJ. The global health dimensions of asbestos and asbestos-related diseases. Ann Glob Health 2016; 82: 209–13
[122] Global Burden of Disease (2020). GBD results tool. http://ghdx.healthdata.org/gbd-results-tool. Accessed 6 May 2021.

Supplementary materials: Summary of HPAP Process and Outcomes to date

The aims of the Health and Pollution Action Plan process are to:

1) Identify and evaluate the health impacts of pollution within a country;
2) Prioritize pollution issues based on the magnitude of their health impacts;
3) Identify and implement interventions to reduce exposures to the sources of pollution and related health effects.

HPAP process

After initial discussions and responding to a formal request from the relevant ministry (often the ministry of health), an official working group is established in collaboration with key ministries and local agencies, including academics and knowledgeable NGOs.

The HPAP is led by a government agency and is structured to bring together agencies and parties who usually do not interact. HPAPs provide an opportunity for different stakeholders to share and review national reports, policies, journal articles and other relevant information on health and pollution. The objective of the process is to achieve a consensus through consultation, building on existing interventions, and identifying potential areas of collaboration. The initial HPAP process is completed at a final validation workshop where it is approved by the relevant agencies and other critical stakeholders.

The outputs are project proposals which can be commenced with local resources. The final HPAP report and project proposals are also used to generate support for wider action from the national government and external partners.

The following table provides a summary of HPAPs completed or nearing completion, based on information from the Global Alliance on Health and Pollution (GAHP). The progress, scope and outcomes of the HPAP in each country differ according to local conditions, enthusiasm of key parties and availability of resources.

Country (donor)	**Priority Issues identified**	**Concept Notes/Project Proposals developed**
Colombia (co-led by UNIDO and Pure Earth, funded by the EU and USAID) Completed Dec 2018	Ambient urban air pollution ($PM_{2.5}$) National capacities to address endocrine disruptors Pesticide contamination of food Sites contaminated by chemicals	Developing the country's roadmap for the reduction of $PM_{2.5}$ emissions and building technical capacities for monitoring and follow-up. Elaboration of a strategy for the prevention/mitigation of health risks associated with Endocrine Disruptors among vulnerable populations in Colombia

		Strengthening of the country's institutional coordination for the inspection, monitoring and control of pesticide residues in food National Contaminated Sites Identification and Screening Program (aims to establish the first database in Colombia)
Ghana (led by UNIDO, funded by EU and USAID) Completed May 2019	Municipal Waste Management Industrial Pollution Toxic Pollutants of all forms at contaminated sites	Sustainable Waste Management Pilot in Kumasi National Contaminated Site Identification and Assessment Project: updating the existing database and identifying and screening additional sites. The project will also generate a Ghana pollution map and pilot remediation at 2 pilot sites. Resource Efficient Cleaner Production (RECP) in the Chemu catchment area to enhance their operational productivity while at the same time reducing their impacts on the Chemu Lagoon.
Kyrgyzstan Completed May 2019	Air pollution in Bishkek Water pollution in the Issyk-Kul Oblast	Reducing harmful pollutants from transport in Bishkek Upgrading water quality monitoring of Lake IssykKul by improving and modernizing water quality monitoring of Lake Issyk-Kul and its main tributaries
Madagascar	Household air pollution	Pilot-Scale Household Air Pollution Reduction. Aim is to identify and to begin to implement interventions that can measurably reduce HAP

Completed Oct 2018	Ambient urban air pollution ($PM_{2.5}$) Identification and assessment of chemical contamination	Upgrading Transportation Fuel Quality. Roadmap illustrating the costs and benefits of upgrading the quality of fuel imported to Madagascar and the functional steps the government and private sector would take. National Contaminated Site Identification and Screening Program to identify and screen sites across the country where soil and water pollution pose public health risks
Philippines Completed March 2019	Outdoor Air Pollution Wastewater and Sanitation Occupational Exposure Indoor Air Pollution Soil Contamination	Mitigating Pollution from the Transport Sector Continuing to reduce Water Pollution in Manila Bay Reduction of lead exposures from used lead-acid battery recycling activities Improvement of Indoor Air Quality from Household Energy Use
Tanzania (led by UNIDO and funded by EU and USAID) Completed Feb 2019	Water and waste water pollution Indoor air pollution Outdoor air pollution Exposure to chemicals from agriculture	Air Quality Management for Improving Human Health and Environment in Urban Cities and Municipalities Wami-Ruvu Basin Water Quality Improvement Project Reducing exposure to Heavy Metals and other Toxics in Small Scale Mining

	Exposure to heavy metals from mining activities	Reduction of Indoor Air Pollution and its impact on Health of Women and Children in Vulnerable Rural and Urban Communities Sound management of pesticides in agronomy for protection of human health in Tanzania
Thailand Completed May 2019	Ambient air pollution in Northern Thailand Chemical contamination	Pathways to beat air pollution to deliver health benefits in Thailand National Contaminated Site Identification and Screening Program
Kalimantan Province, Indonesia Completed May 2020	Smoke pollution from forest and land/peat fires Mercury pollution in Small Scale Gold Mining (ASGM) Pesticide pollution in agriculture and plantations	Reducing the health impacts of Smoke Pollution from Kalhutra (Forestand Peatland fires) by streamlining the coordination system of the relevant local agencies; collecting data on health impacts and economic losses; and then develop community education and awareness to take action in areas prone to Kalhutra Strategy for the mitigation of health risk associated with mercury pollution among the vulnerable population in Central Kalimantan, including to assist local governments in RAD (Regional Action Plans) for Removing Mercury, which was initiated by DLH together with Artisanal Gold Council. This project will help build the capacity of local governments to collect data and increase awareness of the dangers of mercury for the environment and health in vulnerable areas or populations. Developing Central Kalimantan Province's roadmap for reducing health risks of pesticides pollution by building the technical capacity for the development of program

		intervention and raising awareness of the community and employees of the plantations. The government is expected to gradually increase public awareness to switch to using natural or more environmentally friendly pesticides.
Senegal Completed Sep 2020	Heavy metals pollution (lead and mercury) Pesticides pollution Effects of pollution on Health in Senegal	Decontamination Project for Saint-Louis and Richard-Toll Pesticide Storage Site Study on the prevalence of Asthma in the school environment in Dakar in relation to indoor and outdoor air pollution Project to assess the exposure of women and children to mercury in gold panning areas in the Kédougou region Project to assess stakeholders (operators, recyclers and garages) and practices in the used oil and battery sector, and to raise awareness of good practices.
In Progress Bangladesh Tajikistan Azerbaijan	Priority issues have been identified through the HPAP process in each country but final acceptance and validation by all stakeholders has not yet been formalised	Selection and approval of interventions and projects will be finalised when the HPAP has been validated and reviewed by the Government.

Supplementary materials: Analysis of country framework documents

This supplemental section provides details and references on the text analysis processes.

Latent Dirichlet Allocation Analysis Methods

Latent Dirichlet Allocation is a machine learning algorithm capable of modeling a text document's subject matter. Through repeated sampling and optimization of Dirichlet parameters, it provides a continuous probabilistic distribution of words over a certain number of topics.[1] Simply put, it models the probability that a word appears in each of the topics and the probability that a topic appears in each of the documents. More details specific to the two applications are provided below.

All data and analysis were performed in R and utilized Latent Dirichlet Allocation (LDA).[2] We also used several R packages: "textmineR" for LDA analysis[3], "SnowballC" for word stemming[4], and "pdftools" for reading pdf files[5], as well as "tidyverse"[6] and "dplyr"[7] for data cleaning and visualization.

World Bank Group, UN, and SDG Country Strategy Document Assessment

Collection

We collected 537 World Bank documents (written between 1995-2020), 136 Asian Development Bank (ADB) documents (written between 1995-2020), 23 Inter-American Development Bank (IADB) documents (written between 2015-2019), and 164 African Development Bank (AfDB) (written between 1999 – 2020) to form a "composite" grouping of the World Bank group documents. We added ADB and AfDB country partnership frameworks to the pool of World Bank frameworks if they represented a country that was not already represented for that year in the World Bank documents. We did not include IADB frameworks in this composite because its shorter timeframe might promote over-representation of certain countries in more recent years.

Similarly, we collected 207 UN documents (written between 2000 – 2020) and 112 Sustainable Development Goal (SDG) country voluntary reviews (written between 2016 – 2020). The UN documents were used for primary analysis.

Latent Dirichlet Allocation (LDA)

LDA, performed with every year of country frameworks, can provide the probabilities for whether "pollution," "biodiversity," and "climate" would appear in each framework and amongst all frameworks for each year. This included finding the probability the word would appear for each topic, and each topic's frequency, for each of the country frameworks and in total. We present these probabilities as the estimated "percent of total subject matter dedicated" to that term.

After performing this analysis separately for each year, we regrouped documents into a 2015-2020 pool and repeated this analysis for "water," "toxic,", "radioactive," "pollution," "pesticides," "particulate," "metal," "mercury," "household," "fossil," emission," "chemical," "burn," "ambient" to provide an overview of each word's percent of subject matter from 2015.

References

[1]Blei, D., NG, A., & Jordan, M. (2003). Latent Dirichlet Allocation. Journal of Machine Learning Research, 3, 993–1022.
[2]R Core Team. (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing. http://www.R-project.org/
[3]Jones, Tommy (2019). textmineR: Functions for Text Mining and Topic Modeling. R package version 3.0.4. https://CRAN.R-project.org/package=textmineR
[4]Bouchet-Valat, Milan (2019). SnowballC: Snowball Stemmers Based on the C 'libstemmer' UTF-8 Library. R package version 0.6.0. https://CRAN.R-project.org/package=SnowballC
[5]Ooms, Jeroen. (2020). " pdftools: Text Extraction, Rendering and Converting of PDF Documents." https://cloud.r-project.org/web/packages/pdftools/index.html
[6]Wickham et al., (2019). Welcome to the tidyverse. Journal of Open Source Software, 4(43), 1686, https://doi.org/10.21105/joss.01686
[7]Wickham H et al., (2019). dplyr: A Grammar of Data Manipulation. R package version 0.8.3. https://CRAN.R-project.org/package=dplyr

Supplementary material: Methods for media analysis

Methodology - Media Coverage of Pollution

Factiva, a media database owned by Dow Jones, was used for data analysis. Factiva aggregates content from both licensed and free sources from nearly every country worldwide.

Broad search parameters used as follows:

- Date range: 7/15/2010 to 31/12/2020
- Language: English only
- Regions: All

Media sources:

- As opposed to creating a custom media list that involves some subjectivity, we utilized an established Factiva list of top news sources
- This list was modified to remove less relevant types of coverage, including: press releases, recurring pricing and market data, obituaries, sports, calendar postings, personal announcements, letters, weather news, food items and routine traffic reports
- Republished news stories were NOT excluded, in order to account for the impact of stories that run in a wire or influential source and are further reported across additional outlets
- Unless otherwise noted, the searches were conducted within the entire article vs. the headline/lead paragraph only

Detailed Search terms

Coverage of modern disease-causing pollution over the 10-year timeframe

1. The search terms used for this portion are:

(pollution OR pollutant* OR emission OR waste OR toxic* OR exposure). Then, within the same paragraph one of the following: (ambient OR chemical OR air OR soil OR water OR radioactive OR pesticide OR herbicides OR insecticides OR particulate OR coal OR industr* OR burn OR fuel OR factory OR environment* OR ozone OR hydrocarbons OR arsenic OR mercury OR lead OR metal OR electronic OR slash OR mining OR petroleum OR vehicle* or electric* OR agricultur* OR exhaust OR urban OR gas)

Note: When removing the "same paragraph" requirement, meaning an article was counted if a term from the first list and a term from the second list appeared anywhere within the article, the article count rises to ~9.5 million. The proximity requirement helped narrow down relevance.

2. To assess which portion of the coverage contained modern disease-causing pollution as a key focus vs. passing mention, we ran the same search limited to the headline and first paragraph of each article vs. the full article search. This amounted to just under ~1.5 million articles, or nearly 27% of the overall coverage.

To determine the frequency with which modern pollution is linked to disease in coverage, we further limited the core initial search to those mentioning one of the terms as follows: disease* OR death or disability OR health OR kill* OR fatal*

Coverage was also assessed to determine the portion including mention of regulations, legislation, interventions, policy, or reform. This accounted for over 34% of the broader set of coverage on modern disease-causing pollution. The top 5 regions for these stories were: U.S., UK, India, China and Canada (same top 5 list as the broader set of coverage, though in this subset, UK surpassed India)

The core search was also assessed when limited to “developing economies” vs. “all regions” and this accounted for ~28% of the coverage globally

“Developing economies” is defined in Factiva as countries listed as low-income, lower-middle-income, or upper-middle-income economies per the World Bank.