Environmental Change and Human Health: an Assessment of the Economic Significance of Global Warming and Air Pollution for Planetary Health

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Rockefeller Foundation Economic Council on Planetary Health

Environmental Change and Human Health

An assessment of the economic significance of global warming and air pollution for planetary health

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A report prepared for the Secretariat of the Rockefeller Foundation Economic Council on Planetary Health at the Oxford Martin School

Cover photo: Particle Pollution in Easter China. NASA image created by Jesse Allen, Earth Observatory, using data obtained from the MODIS Rapid Response team, available online at: https://earthobservatory.nasa.gov/images/13919/particle-pollution-in-eastern-china

Introduction to Planetary Health

Planetary health is a multi-disciplinary approach that addresses the interconnections between the processes of environmental change and their impacts on human health and well-being, at scale. The planetary health concept builds on the ecological framing of planetary boundaries and supports the UN Sustainable Development Goals and the Paris Climate Change Agreement, both of which recognize the importance of regional and global coordination to solve complex environmental and development challenges.

Links between environmental change and human health are both direct (e.g. impact of air pollution on respiratory and cardiac functioning) and indirect (e.g. extreme weather events or sea-level rise leading to permanent displacement) but there is plausible connection between the change in natural systems and human well-being. The planetary health approach requires transboundary perspectives covering issues that one country cannot address in isolation. Solutions, however, may be local, national, regional or international.

The work of The Rockefeller Foundation Economic Council on Planetary Health, through its Secretariat based at the Oxford Martin School at the University of Oxford, aims to provide a policy-oriented, economic perspective to developing solutions. The central economic concept is that externalities – or costs and benefits to another party that are not priced, regulated or consented to – should better address planetary boundaries than at present. The analysis pays attention to equity and distributional issues, recognising how different people, institutions, countries and trajectories of development are affected by the impact of planetary health and the measures proposed to address it. This work seeks to target recommendations at global and national policy-makers.

A series of background papers has been developed by the Secretariat. These papers aim to illustrate where solutions might be identified and applied, diagnosing planetary health issues by highlighting drivers of change, significant environmental impacts and the resulting human health impacts.

This paper explores the health impacts of global warming and air pollution: two key planetary health issues. The report shows that air pollution is already a significant contributor to global mortality, and in the coming decades, global warming is also predicted to have greater health impacts, including increased mortality. In both cases, climate change mitigation and the transition to clean energy have significant potential to reduce the health impacts of these two planetary health issues.

Sam Bickersteth
Executive Director, The Rockefeller Foundation Economic Council on Planetary Health

The full set of papers can be accessed at: *www.planetaryhealth.ox.ac.uk/publications*.

Executive Summary

This short report is composed of two standalone factsheets on the health impacts of global warming and air pollution. A review of the most up-to-date scientific evidence shows that global warming is expected to lead to 250,000 extra deaths every year by 2050. This figure assumes some mitigation. In the absence of any mitigation, the expected figure would more than double. In parallel, exposure to ambient air pollution is currently killing at least 7 million people annually. Increasing trends in exposure to ambient air pollution in low- and middle-income countries suggest that this figure will soar in the future.

The health impacts of global warming and air pollution tend to concentrate in developing countries, especially in Southeast Asia, the Eastern Pacific and Sub-Saharan Africa. Both urban and rural areas are impacted, with some effects (e.g. ambient air pollution) being more present in cities, while others (e.g. negative impacts of climate change on agriculture) put rural areas at increasing health risk. In fact, climate change and air pollution are two sides of the same coin because they share the same main driver: the burning of fossil fuels. The transition to cleaner energy is therefore the most straightforward solution capable of coping with the health burden of these two planetary health issues at the same time.

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Contents

1. Global Warming and Planetary Health

Highlights:

- Current estimates suggest that global warming is likely to result in 250,000 extra deaths every year by 2050 under a medium-high emissions scenario (RCP 4.5).
- Most extra deaths would be in emerging countries already exposed to warm temperatures, especially in Southeast Asia and possibly Africa.
- In addition, mortality is at risk of soaring if warming exceeds a reasonable range, causing up to 3.9 million deaths by 2100 in a high emissions scenario (RCP 8.5).

Introduction

The current pledges by the signatories to the Paris Agreement add up to no more than a third of the reductions needed to limit temperature increases to 2°C (UNEP, 2017). Therefore, some climate change will almost inevitably occur in the 21st century. The health burden of global warming will be high. Several global estimates for the impact of global warming on health are available. The WHO (2014) estimates that 250,000 deaths annually will be imputable to climate change in the next decades (2030-2050) because of malnutrition, malaria, diarrhoea and heat stress. Using a different method, Carleton et al (2018) reach the same figure of 250,000 extra deaths every year in 2050 under RCP 4.5 (medium-high emissions scenario) (own calculations based on Carleton et al., 2018, Global Burden of Diseases (GBD) data and UN 2017 population forecast). As more warming would happen until 2100, the death toll would reach around 550,000 extra deaths in 2100. Yet, these large estimates assume some climate change mitigation. In the worst scenario of no mitigation (RCP 8.5), extra deaths would already reach 550,000 in 2050 and soar to 3.9 million annually in 2100 (figures based on Carleton et al., 2018). Health impacts would become extreme if heat waves became the norm. Note that these figures do not account for sea level rise or catastrophes such as cyclones and thunderstorms. They also mask large distributional effects between cold and warm countries. Finally, they are the tip of the iceberg since mortality is the most extreme health outcome. Increased morbidity, birth rate reductions and productivity losses are additional effects that climate change could have on health.

Mechanisms

The mechanisms relating climate change to health are complex (see Figure 1).

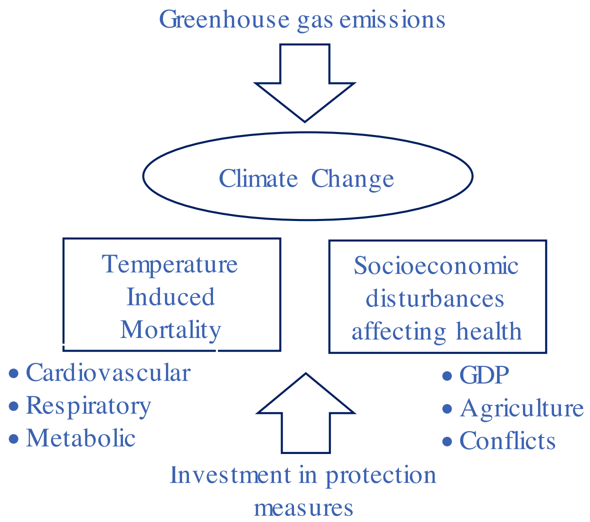

Figure 1: Global Warming as a Planetary Health Issue

Climate is a component of environmental health. Direct exposure to cold and heat beyond the comfort zone of the human body puts additional pressure on cardiovascular, respiratory and metabolic systems. In addition, our climate shapes economic outcomes, e.g. agricultural output and GDP. Economic difficulties arising from bad weather influence conflicts and political stability, with long-run consequences on health. Climate change is a planetary health issue because it is provoked by human activity, principally greenhouse gas emissions from fossil fuel combustion. However, we can respond to climate change through mitigation and adaptation.

Direct Impacts of Global Warming

Our environment has a strong and direct impact on human health. At present, direct exposure to cold has a stronger influence on human health than exposure to heat. Gasparrini et al. (2015) estimate that 7.29% of deaths globally (≈3.9 million annually) are imputable to cold, versus 0.42% for heat (≈225,000 annually). The effect of climate change on the distribution of cold and heat related mortality is subject of debate. The evidence reviewed in IPCC (2018) is that cold-related mortality will reduce, but heat-related mortality could soar if climate change is extreme (RCP 8.5). For this case, the OECD (2015) estimates that a million deaths annually could occur from heat stress by the 2050s, and close to 3 million by 2080. At lower levels of climate change, the net mortality effect of direct temperature exposure is uncertain because heat-related mortality amplifies at very high temperatures only. For Mexico, Cohen and Dechezlepretre (2017) find that cold is the main driver of direct weather-induced mortality and that climate change might reduce mortality from temperature exposure by 30% in 2100 under the RCP 4.5 scenario.

Indirect Impacts of Global Warming

Because climate change will disrupt economic systems, a large share of the health burden of climate change could come through indirect channels. There is consensus that the health burden of warmer days will exceed the drop in cold-related mortality when indirect channels are taken into account. The study by Carleton et al. (2018), who find about 250,000 extra deaths per year under RCP 4.5 by 2050 accounts for these indirect channels. Furthermore, the indirect health impacts of climate change should rise steadily through the second half of the century since temperature will keep on increasing. By 2100, the estimate by Carleton et al. (2018) is twice higher than for mid-century (550,000 extra deaths per year under RCP4.5).

Global econometric studies like Carleton et al. (2018) do not specify which indirect channel relates climate change to health. Adverse effects to **agriculture** are likely to concentrate the largest share of indirect deaths. A 1°C temperature rise is expected to cause a 6% and 10% decline in global wheat and rice production, respectively (Smith et al 2014). Springmann et al. (2016) estimate that climate change will cause around 370,000 deaths per year by 2050 under RCP4.5. This is because of a reduction in global food availability and changes in the nutritional quality of diets. This figure overshoots the one of Carleton et al. (2018), suggesting that the indirect effects on agricultural systems alone could overshoot any reduction in mortality associated with direct temperature exposure.

Furthermore, the impact of climate change on **economic outcomes** correlating with good health, especially in developing countries, is likely to encompass many additional factors that cannot be easily tracked. Yet, Dell, Jones, and Olken (2012) find that being 1°C warmer in a given year reduces per capita income by 1.4 percent, but only in poor countries. Hsiang (2010) found similar results in twenty-eight Caribbean-basin countries over the 1970–2006 period. National output falls 2.5 percent per 1°C warming. This echoes the microeconomic evidence that labour supply (Dunne et al., 2013; Graff-Zivin and Neidell, 2014) and productivity (Hsiang, 2010; Somanathan et al., 2014) are impaired by heat stress and sustained heat.

Scarcer food and lower economic outputs could affect **political stability and violence**. Hsiang, Burke and Miguel (2013) find that a 1 standard deviation increase in temperature increases the rate of interpersonal violence by 2.3%, and increases in the rate of intergroup conflict by 13.2%. By 2050, they predict that climate change corresponds to increases temperature in the range of 2-4 standard deviations. Using the GBD data and UN population forecast, we can calculate that this may represent 60,000-120,000 additional deaths per year.

The health burden of climate change will also go beyond mortality, which is the tip of the iceberg and may hide significant increases in morbidity. **Vector-borne diseases** are affected by temperature changes. In the case of malaria, Dasgupta (2016) estimates a median change in all-age malaria mortality by up to 2.5% by the end of the 21st century under the RCP 8.5 scenario. This is a relatively small mortality impact (<20,000 deaths since 445,000 people died from malaria in

2016). However, the impact on morbidity could be fierce. For this same year, 216 million malaria cases occurred, 2.5% of which correspond to 5.4 million cases.

Likewise, **mental health and wellbeing** could be very strongly impacted by climate change, e.g. because of forced migration caused by agricultural losses, or increased income uncertainty. At the extreme end, suicide rates have been found to correlate with temperature increases in the US and Mexico (Burke et al., 2018) and in India (Carleton, 2017). Midler impacts may have equally adverse welfare effects. Already, high outdoor temperatures have been found to increase negative reactions in tweets on the internet, suggesting a link between temperature and mood (Baylis, 2015).

Climate change may also reduce ***fertility***. Deschenes, Greenstone and Guryan (2009) show that birth weight may decrease in the US as a result of climate change at the end of the century. While the impact of climate change on fertility globally is unknown, climate change may in fact prevent births from happening.

Heterogeneity of impacts across populations

The mortality reductions from exposure to cold will be stronger in colder regions, while the health burden of heat stress will significantly affect warmer regions (Gasparrini et al., 2015; Carleton et al., 2018). Because warmer regions tend to be poorer regions, inequalities in mortality between industrialized and emerging economies are expected to widen because of climate change. Within countries, mortality inequalities should also widen between the rich and the poor. Income plays a significant role in weather vulnerability because richer households can protect themselves in many ways, first against the direct impacts of cold or heat, but also against indirect impacts, e.g. because they have access to savings and/or financial markets (Burgess et al., 2014; Cohen and Dechezleprêtre, 2017; Carleton et al., 2018).

Schematically, the current differences in exposure to heat and income levels imply that most of the morbidity and extra deaths from heat stress plus the indirect deaths from agriculture and conflict, to be expected every year by 2050, may exclusively concern people in warmer developing countries. As an example, India and China would respectively concentrate 26% and 47% of the climate-related deaths associated with agriculture (Springmann et al., 2016). Subsistence farmers will almost certainly be the first affected. Some other effects, such as an increase in the prevalence of malaria, will be almost exclusively borne by African and Asian countries. In parallel, the epidemiologic evidence points out that weather-vulnerability is much stronger among young children (<5) and the elderly (>70). This means that ageing societies and high-fertility countries, especially the least developed countries, will be more vulnerable.

The health benefits of mitigation and adaptation

The evidence suggests that avoiding climate change altogether would therefore save 250,000 lives compared to RCP 4.5 (medium-high emissions). The benefits of mitigation are even sharper when we consider the risk of no mitigation at all (the RCP 8.5 scenario). No mitigation would entail a dramatic death toll of up to 3.9 million people by 2100. This figure is based on Carleton et al. (2018) who estimate an effect of 36 extra deaths per 100,000 in 2100 under RCP 8.5. Already limiting emissions to medium-high levels as under RCP 4.5 reduces the health burden to climate change by 80%.

For the part of climate change that may not be avoided, private and public initiatives could still substantially reduce the health burden of direct exposure to hot weather. For the US, Deschênes et al. (2011) predict that temperature rises will lead to a 3% increase in mortality, which they qualify as a rather moderate increase. In parallel, they predict an 11% increase in annual residential energy consumption. They interpret the change in energy consumption as immediate adaptive response to high temperatures (with air conditioning). Longer-run adaptation strategies could include investments in cooling equipment and energy efficiency or even the migration to colder regions (Deschênes et al., 2011; Cohen et al., 2017). Similarly, Barreca et al. (2015) find that US mortality rates significantly dropped concomitant to the adoption of air conditioning. Public policies may also be able to play their part in protecting population against inclement weather. Cohen and Dechezleprêtre (2018) find that healthcare extension reduced weather-related mortality by 13% in Mexico. Additional protection measures could include policies targeting diet (Springmann et al., 2016) to reduce risks associated with cardiovascular and metabolic diseases. More generally, this analysis has focused on changes in temperature, but some disasters like floods and cyclones could become more frequent under climate change. Disaster preparedness and investments against catastrophic risk could save also lives (e.g. Hallegatte et al., 2015).

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2. Air Pollution and Planetary Health

Highlights:

- Air pollution is estimated to cause at least 7 million deaths annually.
- Current calculations are likely to underestimate deaths.
- The health burden disproportionally falls on Southeast Asia, the Eastern Pacific and Sub-Saharan Africa.
- Pollution reduction depends on the transition to clean energy that is part of climate change mitigation.

Introduction

Air pollution is currently responsible for an estimated 7.1-7.5 million premature deaths worldwide every year (GBD, 2015; WHO, 2014, 2018a). Indoor pollution caused by the combustion of solid fuels for cooking and heating is as deadly (with 2.9-3.8 million deaths) as the exposure to the ambient air pollution (with 3.7-4.2 million deaths) formed by pollutants. The main pollutant analysed in these global mortality studies is Particulate Matter ($PM_{2.5}$), but its presence correlates with other major pollutants. Air pollutants are known to considerably increase the risk of acute respiratory infections, stokes, heard diseases and lung cancer. Children face the highest health risks of air pollution as their bodies are still developing and are sensitive to develop respiratory diseases (Currie et al. 2014; WHO, 2018b). Air pollution is known to unequally affect the rich and the poor. Low- and middle- income countries record approximately 90% of deaths from ambient air pollution because of high concentrations of pollutants in these areas (WHO, 2018c), with Southeast Asia recording the most alarming exposure levels. Within countries, low-income groups are exposed to higher pollution levels. They are more likely to live in the proximity of highways or industrial sites (Havard et al. 2009). The health burden of pollution goes beyond mortality and morbidity. It is responsible for productivity losses, absenteeism and leads to high increases in health expenditures. The welfare cost of pollution has been estimated to be 6.2% of global GDP (Landrigan et al, 2017).

Sources of Air Pollution

Power generation, industrial activities, road transport and agriculture are the main sources of ambient air pollution (see Figure 2). Activities involving the burning of fossil fuels account for most of ambient air pollution. The combustion of fossil fuels and biomass accounts for 85% of PM emissions (Landrigan et al, 2017). Nitrogen Oxides (NO_x) and Sulphur Dioxide (SO_2) pollutants are largely emitted by the transport and energy sector. US estimates for 2010 show that about 1/3 of NO_x emissions and 2/3 of SO_2 emissions are produced by transport and coal power plants, respectively (OECD, 2016). Ozone (O_3) is a gas not directly emitted but produced though chemical reactions between other pollutants, in particular NO_x and volatile organic compounds (VOC). An increase in NO_x emissions will therefore increase O_3 levels. Sustainable development, in particular a transition towards using clean energy encouraged with regulatory and market-based instruments, would considerably reduce the health burden of air pollution and its economic cost.

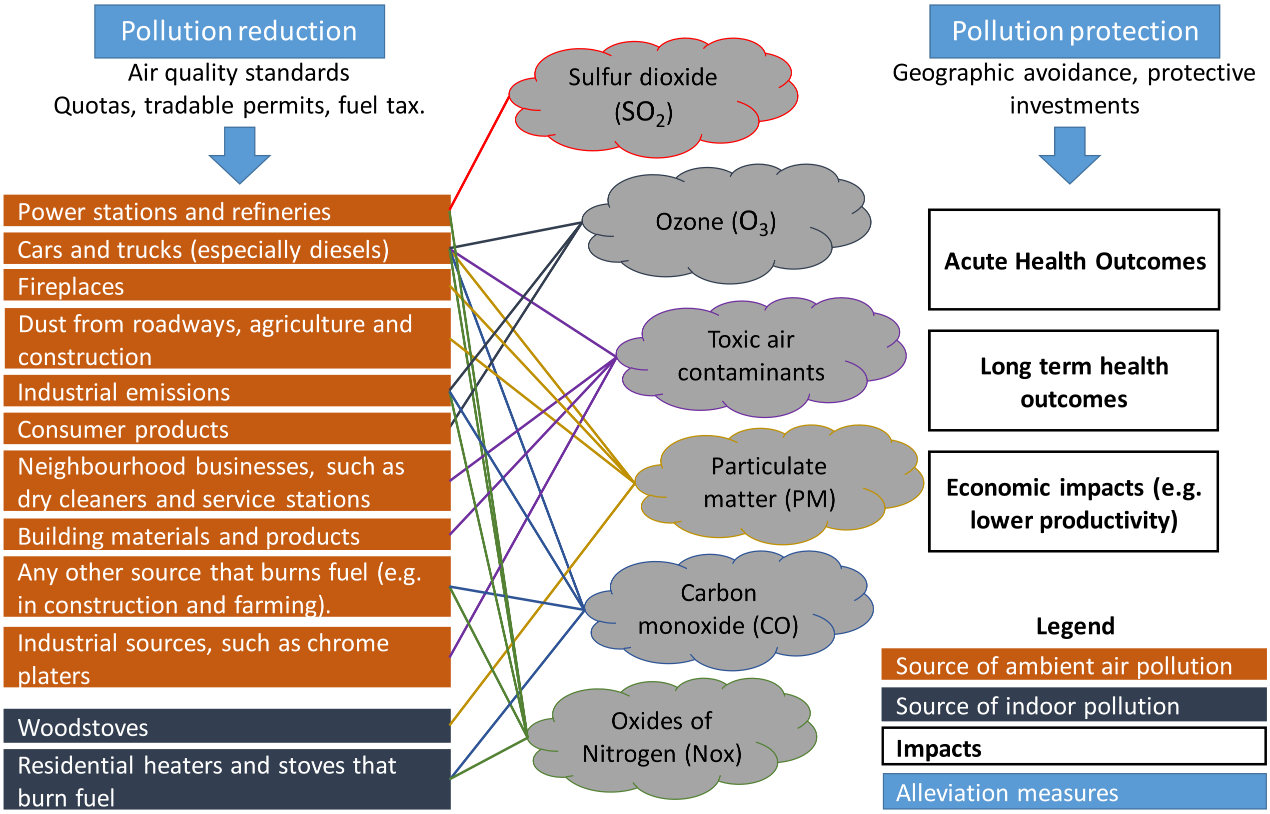

Figure 2: Pollution sources and alleviation measures

Sources: Own construction based on information from EEA (2016), Defra (2018) and California Air Resource Board (2018).

Exposure to Air Pollution

56% of cities in high-income countries and 98% in low- and middle-income countries do not meet WHO air quality guidelines (WHO, 2016a). The situation is dramatic in many parts of South East Asia and Africa (see Figure 3). Unfortunately, global urban air pollution levels have increased by 8% over the period 2008-2013 and are expected to rise in many of the world's poorest cities (WHO, 2016a). This is a consequence of population growth and economic development. While cleaner energy and transport will reduce negative health outcomes in the US and Western Europe, China and India will be confronted with higher power plant emissions and road traffic (OECD, 2016).

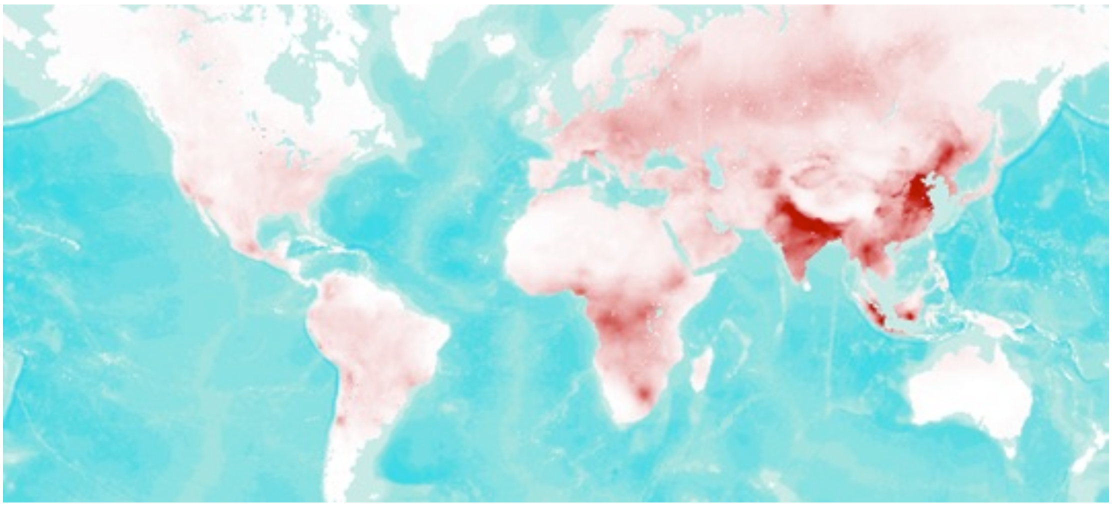

Figure 3: Particulate matter concentrations in 2016

Sources: Annual PM2.5 concentration are from NASA satellite imagery: Global Annual PM2.5 Grids from MODIS, MISR and SeaWiFS Aerosol Optical Depth (AOD) with GWR, 1998-2016. Concentration range from 0 (in white) to 127µg/m3 (in dark brown). Base map showing continents and oceans is from Esri, USGS, NOAA and NPS.

Indoor pollution is of particular concern in low-income countries. The combustion of solid fuels for cooking and heating releases heavily health-damaging particulates. At present, the use of these fuels concerns about 3 billion people (WHO, 2018b): 79% of the people in Africa, 63% in South-East Asia and 40% in the Eastern Pacific. Solid fuels are widely used in African cities (e.g. 60% of urban households in Cameroon), whereas users concentrate in rural areas in the rest of the world (e.g. 81% of rural households use solid fuels vs. 26% of urban ones in India) (WHO, 2015).

Downward Bias in Mortality Estimates.

Three widely cited reports (GBD, 2015; WHO, 2016b and 2016c) provide estimates for the mortality impact of air pollution globally: respectively 4.2 and 3.7 million deaths from ambient air pollution in the GBD study and the WHO study; and respectively 2.9 and 3.8 million deaths for indoor pollution. Exposure to outdoor and indoor pollution takes place simultaneously and reinforces each other (OECD, 2016).

The global mortality figures are based on a meta-analysis of the epidemiological studies on the matter. The reliability of the GBD and WHO estimates therefore depend on the quality of the epidemiological evidence gathered so far. There is consensus that the epidemiological evidence underestimates the mortality impact of pollution, even though the extent of the underestimation is unknown. First, the GBD and WHO estimates are largely restricted to effect of PM2.5, underestimating the effect of other pollutants. Second, there are difficulties to characterise long-term health consequences with the statistical techniques and data available. Most high-quality estimates capture short-term exposure. Third, pollution exposure is often miss-measured, in particular in low- and middle-income countries. Miss-measurements are known to attenuate mortality estimates. Using methods that deal with measurement error, Arceo et al. (2016) find mortality responses that are 2-4 times stronger in Mexico City compared to when measurement error is not accounted for. These points suggest that the estimates of 7.1-7.5 million premature deaths due to pollution are lower bound estimates.

Other Impacts of Air Pollution

The economic literature has shown that the socioeconomic impacts of air pollution are pervasive, amounting to as much as 6.2% of global GDP annually (Landrigan et al, 2017). Especially, worker productivity is impaired. Graff-Zivin and Neidell (2012) find that a 10-ppb change in average ozone exposure reduced agricultural worker productivity by 5.5%. Hanna and Oliva (2015) find that the closure of a large refinery in Mexico City led to a 19.7% decline in SO2 pollution leading to a 3.5% increase in working hours. Air pollution is also known to affect learning abilities of children. Currie et al (2009) find that reductions in high CO days decreased absences in schools by 0.8 percentage points in Texas. Estimates for Israel show that higher exposure to PM2.5 and CO levels are negatively related to test scores and college entry (Lavy et al., 2014). Effects on human capital accumulation start as early as in the womb. Bharadwaj et al. (2017) find a strong negative effect of fetal exposure to CO on math and language skills in 4th grade. Almond et al. (2009) look at radioactive particles from Chernobyl passed over to Sweden. The exposure reduced overall grades and mathematics scores by 2.5 and 6 percentage points respectively. Other, less documented impacts may exist. For example, the OECD (2016) suggests that reduced visibility and damages to cultural heritage may influence changes in tourism and leisure patterns.

Pathways towards Pollution Alleviation

The development pathway that low- and middle-income countries may take in the coming decades will be essential to reduce the health burden of both household and ambient air pollution. Rising income levels are expected to facilitate the switch to cleaner fuel sources reducing the negative effects of outdoor and indoor air pollution (OECD, 2012 and 2016). However, exposure to ambient air pollution is still expected to increase and the associated mortality could soar to 6-9 million in 2060 if stringent policies are not implemented (OECD, 2016).

Climate change mitigation offers a unique opportunity to tackle ambient air pollution. All countries have agreed to reduce global warming to less than 2°C under the Paris Agreement. If achieved, climate change mitigation would entail a strong increase in low carbon energy, to around 60% of primary energy by 2050, and a necessary decline in fossil fuel combustion, especially coal. It will also put an end to deforestation, the second largest source of PM (IPCC, 2014).

The Lancet Commission notes that pollution prevention can be highly cost-effective, and strategies that proved to be successful can be implemented elsewhere (Landrigan et al. 2017). In the US, the Clean Air Act has found to be very effective and have had health benefit though reduced infant mortality (Chay and Greenstone, 2003; Sanders and Stoecker, 2011). The 1970s ban on leaded gasoline in Sweden reduced lead levels from 10 to 5 µg/dL and increased high school graduation rates by 2.3% and young adult earnings by 5.5% (Nilsson, 2009). In Mexico, policies aimed at reducing air pollution reduced ozone and carbon monoxide concentration by 23% and 48%, respectively, between 1997 and 2006 (Arceo et al 2016). Recent amendments to Chinese air pollution legislation reduced PM2.5 levels by 10% over the period 2014-2016 (Landrigan et al. 2017).

In parallel, initiatives to reduce indoor air pollution are being conducted in low- and middle-income countries. In 2007, the Indonesian government introduced a subsidy that encouraged people to adopt cleaner technologies for cooking. It reduced kerosene use among households by 83% in 4 years and led to a 1-percentage point decrease in the infant mortality rate (Imelda, 2018). A household electrification scheme in El Salvador, in 2009, has led to reductions in indoor air pollution (PM2.5) by 66%, lowering acute respiratory infection among children by 8-14 percentage points (Barron and Torero, 2017). Not all initiatives end up being successful though. Hanna, Duflo and Greenstone (2016) study the effect of a program distributing improved cooking stoves at a relatively low cost in India. Indoor air pollution reduced in the first year of use, but without a big effect on a range of health outcomes. In subsequent years no effect was found on indoor pollution and health outcomes because of poor use and maintenance.

Pollution reduction strategies are a low-hanging fruit in very polluted areas. The health benefits are very high in very polluted areas because they rise more than proportionally to initial exposure levels. For example, Ezzati et al. (2001) find that high indoor exposure to PM10 was extremely detrimental to populations in rural Kenya, increasing exponentially the rate of acute respiratory infections. Meanwhile, there is evidence that households take self-protection measures, especially in heavily polluted cities. Zhang and Mu (2017) find that an increase in ambient pollution in Chinese cities increases purchases of particulate-filtering facemasks. Richer people in urban China are more likely to invest in air filters, which are more expensive than masks (Sun et al., 2017).

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