Chapter 1

The links between outdoor air pollution and economic growth

This chapter first presents the main approaches used in the literature to assess the costs of inaction or benefits of action for air pollution. It then introduces the methodology used in this report to study the economic consequences of outdoor air pollution, using a general equilibrium model for market impacts and results of direct valuation studies for non-market impacts. The chapter also presents an overview of the main impacts of outdoor air pollution, including those related to human health and the environment. It then highlights which impacts and economic consequences are quantified in this report. The chapter ends with a description of possible policy approaches to address outdoor air pollution.

1.1. Introduction

Air pollution is one of the most serious environmental risks, particularly in big cities and highly populated areas where it causes strong negative impacts on human health. Outdoor air pollution has also been recognised to have consequences for the environment, with impacts on crop yields, biodiversity, land and water, and on human activities, with impacts on visibility and on buildings and materials, including cultural heritage.

Previous work shows alarming results on the severe impacts of outdoor and indoor air pollution on human health and in particular on the large number of premature deaths it causes.[1] The most recent Global Burden of Disease (GBD) study finds that air pollution – indoor and outdoor combined – is the top cause of environment-related deaths worldwide and estimates it was the cause of 5.5 million premature deaths globally in 2013 (Forouzanfar et al., 2015; Brauer et al., 2016). This is equivalent to 1 in 8 deaths worldwide. The 2010 GBD study (Lim et al., 2012), WHO (2014) and Lelieveld et al. (2015) estimate that *outdoor* air pollution alone is the cause of 3 to 4 million premature deaths per year at global level. According to WHO (2016), 98% of cities in low- and middle income countries and 56% of cities in high-income countries do not meet WHO air quality guidelines. The precise numbers generated by different studies are variable, reflecting refinements for example with respect to exposure modelling (e.g. the exposure cut-off point, or the slope and shape of exposure-response functions). However, the studies are consistent in showing that air pollution has a substantial effect on health and that it can be associated with several million deaths each year.

The negative impacts of air pollution on health and the environment also lead to high economic costs. OECD (2014) uses the "value of a statistical life" (VSL) to estimate the economic costs of outdoor air pollution. It finds that the cost of the health impacts of air pollution in OECD countries (including deaths and illness) was USD 1.7 trillion in 2010.[2] The cost of the health impact of air pollution in 2010 was estimated to be USD 1.4 trillion in the People's Republic of China (henceforth "China"), and USD 0.5 trillion in India.

It is less clear how the impacts and costs of air pollution will evolve in the coming decades. This report aims to fill that gap by assessing the *costs of inaction on outdoor air pollution* for a baseline projection from 2015 to 2060 at the regional and global level to 2060.[3] It focuses on the future biophysical and economic consequences of air pollution in absence of policies other than the ones that are already in place. The report shows that air pollution will have serious consequences for human health and on economic growth, unless more ambitious policies are put in place. This assessment of the costs of inaction of air pollution underlines the magnitude of the air pollution problem at global level.

The social and welfare costs of indoor air pollution should not be ignored. Indoor air pollution particularly affects poor rural communities with scarce or no access to electricity and that are affected by toxic emissions from cooking stoves, heating and lighting in their homes. Nevertheless, this report only considers outdoor air pollution. The reason is two-fold. First, the health problems associated with indoor air pollution are expected to decrease in the coming decades, even without specific new pollution control policies, as countries develop and access to cleaner energy sources becomes more widespread (cf. OECD, 2012). In contrast, the consequences of outdoor air pollution are expected to become more severe over time if no further policy actions are taken. Second, outdoor air pollution is much more directly related to economic activity, and thus a by-product of economic growth, which is the focus of this report.

The analysis in this report is based on the so-called impact pathway approach. This approach, which was developed under the EC-US Fuel Cycles Study and the ExternE project (ExternE, 1995; European Commission, 2005; US DOE, 1992), calculates the economic costs of air pollution (or the economic benefits of reduced air pollution) starting from emissions, through concentrations, exposure, biophysical impacts and valuation of the economic costs.

Previous studies have used the impact pathway approach in the context of an economic valuation of air pollution, mostly for the United States and the European Union. For the EU, such an approach was used to study the benefits of several Directives and technology options aimed to improve air quality (European Commission, 2013 and 2005; Vrontisi et al., 2016; WHO, 2013a,b; Holland, 2014a,b; ExternE, 1995; Rabl et al., 2014). For the United States, the EPA has evaluated the benefits of the Clean Air Act (US EPA, 1997, 1999, 2011). A series of studies have also been carried out on the costs of health impacts of air quality for specific regions (Matus, 2005; Matus et al., 2008; 2011; Nam et al., 2009; OECD, 2014b) and, for ozone only, at global level (Selin et al., 2009).

The report considers a set of selected impacts on health and agriculture as linked to emissions of key primary pollutants – sulphur dioxide (SO_2), nitrogen oxides (NO_x), black carbon (BC), organic carbon (OC), carbon monoxide (CO), volatile organic compounds (VOCs)[4] and ammonia (NH_3) – and the concentrations of particulate matter ($PM_{2.5}$) and ground level ozone (O_3), which are formed as a result of these emissions. Data on regional emissions for the primary pollutants was obtained from the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) developed at the International Institute for Applied Systems Analysis (IIASA). Given the lack of reliable data at global level, it was not possible to quantify other impacts of air pollution, such as those on biodiversity or cultural heritage, or the direct impact of nitrogen dioxide (NO_2) on human health.

The analysis is based on the OECD's computable general equilibrium (CGE) model ENV-Linkages (Chateau et al., 2014). The ENV-Linkages model is used to construct a socio-economic baseline and to formulate a corresponding projection of future emissions of air pollutants. Emissions of air pollutants are then translated to concentrations of $PM_{2.5}$ and ozone using the atmospheric transportation model TM5-FASST (Fast Scenario Screening Tool) developed at the European Commission Joint Research Centre (EC-JRC). The concentration levels are the main inputs to calculate the biological and physical impacts of air pollution on human health and on crop yields. Impacts of air pollution on crop yields are calculated with TM5-FASST using the methodology of Van Dingenen et al. (2009) while a range of health impacts are calculated expanding the methodology of Holland (2014a,b) to the global level. These projections of the biophysical consequences of outdoor air pollution are then used as input to the ENV-Linkages model to calculate the projected economic costs on gross domestic product (GDP) and production.

This report presents the economic consequences of outdoor air pollution for different types of costs. While the market costs, i.e. those associated with impacts that directly affect the economy, are calculated using the ENV-Linkages model, the non-market costs are monetised using results from stated preference (SP) studies, which directly value the willingness-to-pay (WTP) for a reduction in environmental risks. Considering these two complementary aspects of the economic costs of air pollution makes the results of this report very relevant for policy makers, as both types of costs need to be considered when designing policy responses.

This report is structured as follows. Chapter 2 presents the methodology and modelling framework used for projecting and analysing the costs of inaction on air pollution. Chapter 3 presents the projections of economic growth, emissions, concentrations and biophysical impacts of air pollution. Chapter 4 presents results on the macroeconomic costs of air pollution. Finally, Chapter 5 presents the non-market costs of air pollution, including both mortality and morbidity, and a comparison of market and non-market costs.

1.2. Main consequences of outdoor air pollution

The impacts of outdoor air pollution on health and the environment are linked to high concentrations of fine and coarse shares of particulate matter (PM), ground level ozone (O_3) and other pollutants, such as nitrogen dioxide (NO_2) and sulphur dioxide (SO_2).

PM includes both primary particulates emitted in the atmosphere, such as black carbon (BC), organic carbon (OC), metals, salts and ashes, and secondary particulates, which are formed in the atmosphere from a reaction among precursor gases. The precursor gases of PM include ammonia (NH_3), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and, to some extent, volatile organic compounds (VOCs). Ground level ozone is formed in the atmosphere as a consequence of chemical and photochemical reactions involving precursor gases such as NO_x, VOCs and methane (CH_4).[5]

Concentrations of the pollutants are a composite effect of emissions from anthropogenic and natural sources (dust, sea salt, volcanoes, forest fires, etc.). Some geographical areas, such as the Mediterranean Sea or areas to the south of the Sahara desert, have high levels of natural PM (sea salt and dust). Background concentrations of ozone are always present in the atmosphere, but air pollutant emissions increase concentrations regionally. Concentrations of pollutants also depend on climatic conditions. For instance, sunlight increases the presence of ozone in the atmosphere, while a lack of precipitation leads to higher concentrations of PM.

Several other factors influence concentrations and the possibilities of dispersion of the pollutants in the atmosphere. Characteristics linked to the location of the emissions, such as the volume and geographical location of emissions, the topography of the location, whether the emissions are from fixed or mobile sources, and the presence of winds affect the dispersion possibilities. Chemical characteristics of the pollutants, such as the lifetime of the pollutants in the atmosphere, and the capacity of the pollutants to convert into secondary pollutants, also affect concentrations.

A large share of primary emissions is caused by fuel combustion due to fossil-fuel based power generation, transport, industry, and burning of traditional biomass in the residential sector. Some industrial processes also cause large emissions, especially when there is an extensive use of chemical substances. Significant emissions also come from the use of fertilisers, agricultural waste, savannah burning and forest fires.

Spikes in air pollution and long-term exposure to high concentrations of air pollutants affect human health, causing increase in both mortality (i.e. the number of premature deaths attributable to air pollution) and morbidity (i.e. the increase in the incidences of illnesses due to air pollution). Pollution-related illnesses include lung cancer, cardiovascular diseases (ischemic heart disease and stroke), respiratory diseases (chronic bronchitis and asthma) and chronic obstructive pulmonary diseases (WHO, 2013b; Hunt et al., 2016). The additional cases of illness result in more hospital admissions, medical expenses and absences from work. In turn, the absences from work can lead to a reduced productivity of labour. However, air pollution can also have a direct impact on labour productivity, without resulting in absences from work (Graff-Zivin and Neidell, 2012).

An emerging literature shows that air pollution has additional health impacts on fertility, pregnancy, birth weight, and new-borns and children. Effects on new-borns and children may result in neurodevelopment and cognitive issues, which in turn can affect performance at school, and, further in life, lead to lower earnings.

High concentrations of PM, especially finer particles ($PM_{2.5}$), are the main cause of health impacts, as they can easily penetrate into the lungs and bloodstream. There are also direct health impacts due to high concentrations of other pollutants, such as ozone, SO_2 and NO_2 (see WHO, 2013b; Walton et al., 2015). A recent report by the Royal College of Physicians (RCP, 2016) provides an estimate for the combined effect of PM and NO_2 in the UK of 40 000 deaths per year (±25%), an increase from a generally accepted figure of 29 000 for $PM_{2.5}$ alone. This estimate pays particular attention to the potential for overlap in estimates of mortality from assessment of PM and NO_2 in isolation of each other.

High concentrations of ground level ozone also lead to negative impacts on crops yields, as well as plants in general. As a strong oxidant, ozone is toxic to plants and causes several types of symptoms including markings on the foliage (which can make leaf crops such as spinach or lettuce unsaleable), reduced growth and yield, as well as premature death of the plants.

Air pollution also has other negative effects on the environment, including on forests and biodiversity, water and land. It can lead to reduced visibility ("smog"), which limits vistas in national parks and protected areas, affects safety and human activities, and ecosystems. Finally, acidic and nitrogen compounds in the air can deposit onto land and water, degrading water quality and affecting ecosystems with consequences for food quality (and thus for human health), and for the commercial and recreational use of the affected areas. High nitrogen deposition is now recognised as a major threat to biodiversity and overall ecosystem health (Sutton et al., 2011).

The biophysical impacts of outdoor air pollution entail large economic costs. Impacts on human health dominate the "costs of inaction" on air pollution, representing about 90% of the total social costs for some pollutants (OECD, 2008). The health impacts of air pollution lead to increased health expenditures as well as labour productivity losses. Reduced agricultural output can also cause economic losses especially in areas where agriculture constitutes a large part of the economy. Finally, high concentrations of air pollutants, reduced visibility and damages to buildings and cultural heritage can all have consequences for tourism and hence economic costs due to reduced tourism flows.

While this report only focuses on outdoor air pollution, indoor air pollution also poses serious risks to human health. WHO (2014) estimated 3.7 million deaths attributable to outdoor air pollution, but as many as 4.3 million deaths to indoor air pollution.[6] The most significant source is burning of traditional solid fuels such as coal and biomass (e.g. cow dung and wood) for indoor cooking and heating by households, which cannot afford cleaner fuels. Indoor air pollution is also a concern in developed countries, mainly from releases of chemicals from carpets, furniture and household cleaning products, as well as radon and pesticides. OECD (2012) provides some comparisons of the health effects of indoor compared with outdoor pollution.[7] They find that with raising income levels in emerging and developing countries and improved access to commercial energy sources and to health services, indoor air pollution will gradually become less important in comparison with outdoor air pollution.

1.3. Selected impacts of outdoor air pollution

Ideally the analysis in this report would cover all the impacts and costs of outdoor air pollution described in the previous section. Owing to a lack of available data however, it was only possible to assess the costs of air pollution of a selected number of impacts, which are deemed to be of high importance. This report considers impacts of $PM_{2.5}$ and ground level ozone on human health and on agricultural crop yields, as summarised in Table 1.1.

More specifically, the health impacts considered are premature deaths and increasing cases of illnesses (cardiovascular and respiratory diseases). The market-related impacts modelled in ENV-Linkages are thus increased health expenditures, reduced labour productivity as linked to absences from work due to illness and reduced crop yields, while non-market costs related to mortality and morbidity are calculated separately using results from SP studies.

Table 1.1. **Main outdoor air pollution impact categories**

Impact category	Impacts description	Market impacts	Non-market impacts
Health	Mortality from lung cancer, cardiovascular and respiratory diseases due to high concentrations of $PM_{2.5}$ and ozone		Premature deaths
	Morbidity from lung cancer, cardiovascular and respiratory diseases due to high concentrations of $PM_{2.5}$ and ozone	Increased health expenditures	Disutility (e.g. pain and suffering) due to illness
		Changes in labour productivity due to absence from work for illness	
	Other health impacts, from e.g. low birth weight, pregnancy	Not covered in this report	
	Direct health impacts from NO_2	Not covered in this report	
Agriculture	Damages to crop yields due to high concentrations of ozone	Changes in crop yields	
Tourism, leisure	Changes in tourism and leisure due to e.g. reduced visibility, damages to cultural heritage and health risks	Not covered in this report	
Ecosystems, biodiversity, forestry	Degraded air and water quality, reduced ecosystem health	Not covered in this report	

Impacts on cultural heritage, tourism, leisure activities, forestry and biodiversity could not be included as there is not yet enough information available either to attribute the impacts on air pollution or to quantify the impacts in monetary terms.[8] Some health impacts, such as those on pregnancy and birth weight and the direct effects of NO_2 exposure, were also omitted owing to lack of information.

This report can also only account for a subset of all economic consequences originating from the impacts considered. One prime example of an effect that cannot be included in the modelling framework is the (indirect) economic consequences of premature deaths on labour markets. In principle, labour supply lowers if a person from the working age population dies. Similarly, a premature death can also affect future labour supply through a reduced number of births and hence a decrease in the population. But such endogenous effects are not easily predictable and beyond the scope of the current report. Further, for outdoor air pollution these effects can be expected to be relatively small as the premature deaths mostly concern elderly people, with no effects on the labour force and on future population growth (see also Section 4.3). Therefore, the assumption is taken that mortality does not affect the labour market.

As already discussed, the analysis is limited to outdoor air pollution only and does not consider indoor air pollution. Unfortunately, there is very little literature on the economic consequences of indoor air pollution, especially on those related to "new" chemical sources of pollution, so a robust quantitative assessment is not yet possible.

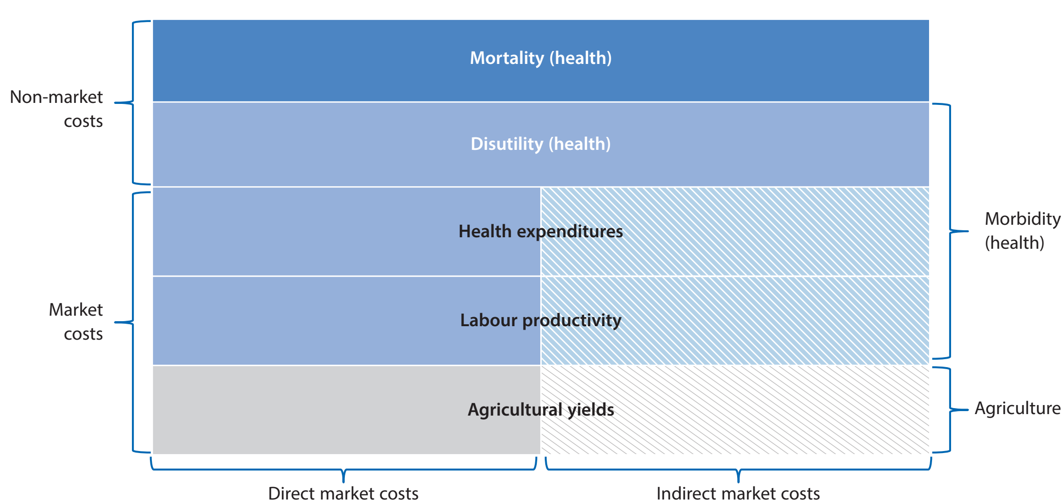
With these missing elements, it is likely that the present report underestimates the costs of air pollution. There are also major uncertainties in the analysis, particularly those involving making projections for future behaviour. Uncertainties exist in the socioeconomic projections, in the projections on the future structure of the economy, via emissions and concentrations of air pollutants to the health impacts and the effects thereof on the economy. While there are important uncertainties at every stage, there is no robust literature to assess which uncertainties are most important for the conclusions of this report. Therefore, the reader should keep in mind the presence of uncertainties throughout the report and in the results presented.

The uncertainties involved in quantitative studies should not unduly deter action, as a number of qualitative insights are robust, most importantly that outdoor air pollution affects health, as demonstrated by repeated epidemiological studies undertaken throughout the world, and that associated impacts on the economy and on welfare are substantial.

1.4. Typology of air pollution costs

This report considers both market and non-market costs of outdoor air pollution. Market costs (i.e. costs to the economy) are those that are associated with biophysical impacts that directly affect economic activity as measured in the national accounts and GDP. For example, lower crop yields affect agricultural production. Non-market costs include the monetised welfare costs of mortality (premature deaths), and of the disutility of illness (e.g. pain and suffering). While market costs show the need to address air pollution policies in order to avoid negative effects on the economy, non-market costs show the – potentially extremely high – social benefits that air pollution control policies can have. Figure 1.1 graphically represents the different types of costs considered in this report.

Figure 1.1. **Cost categories considered in this report**



The market-related impacts, which in this study comprise additional health expenditures due to illness, labour productivity losses due to absences from work for illness, and agricultural yield losses, are included in the ENV-Linkages model to calculate the global and regional costs of outdoor air pollution on GDP and sectoral production. The market costs are further split into direct and indirect market costs. A general equilibrium framework can take into consideration both direct and indirect effects throughout the economy. For instance, a decrease in crop yields will lead to a direct impact on agricultural output of the affected crops, but also to indirect effects, including substitution by other crops and changes in trade patterns. As underlined by Hunt et al. (2016), since the market impacts of air pollution may result in significant effects on related markets or government finances, an economy-wide modelling approach is needed to capture the full economic costs.

Non-market impacts cannot be easily accounted for in a general equilibrium framework as they are not linked to any specific variable in the production or utility functions of the model. The welfare costs of non-market impacts, including both the costs of mortality and morbidity caused by outdoor air pollution, are evaluated using results from SP studies.[9]

To compare market and non-market costs, both types of costs can be expressed in terms of welfare. Non-market costs are directly calculated as welfare costs. Market costs can be expressed as welfare costs using the concept of equivalent variation of income.[10] This, as well as the comparability of the different types of costs, is further discussed in Sections 2.8 and 5.4.

1.5. Possible policy responses to outdoor air pollution

This report only focuses on the costs of inaction of outdoor air pollution. Nevertheless, there are several policy options available to address air pollution. A taxonomy of policy instruments to address air pollution is summarised in Table 1.2, which is reproduced from OECD (2012).

The implementation of policies that reduce pollution levels will certainly address and reduce the biophysical as well as the economic costs of air pollution. These can include incentivising or requiring the adoption of end-of-pipe technologies that can reduce pollution or of cleaner technologies, especially for energy combustion, as well as implementing air quality standards, automobile emission standards, fuel quality standards, and emission taxes, among others.

Table 1.2. **Taxonomy of policy approaches for air pollution management**

Regulatory approaches	Economic instruments	Others
• Ambient air quality standards. • Emission ceilings (e.g. the European Union's National Emission Ceiling Directive). • Industrial emission standards, technology standards. • Reporting requirements for stationary sources (e.g. pollutant release and transfer registers). • Fuel efficiency standards. • Fuel quality standards. • Vehicle inspection and maintenance programmes.	• Tradable permits schemes for air emissions from stationary sources (e.g. SO_2 allowance trading system under the US Clean Air Act). • Fuel taxes. • Road pricing. • Congestion charges. • Taxes on emissions. • Financial incentives for the development of alternative and renewable fuels and advanced transport technologies (e.g. California's DRIVE programme).	• Information collection: - through emission and air quality monitoring; - for cost-benefit analyses to support policy evaluation (with valuation of health impacts); - for public education (e.g. Canada's Air Quality Health Index). • Voluntary schemes (e.g. car-scrapping schemes). • International conventions (e.g. The Convention on Long-range Transboundary Air Pollution). • Infrastructures and urban planning. • Flexible work initiatives (e.g. the US Telework Enhancement Act of 2010).

Source: OECD (2012).

Education, information diffusion, cohesion policies and early warnings can also reduce the impacts of air pollution on health. Cohesion policies can provide support for countries to comply with legislations, develop infrastructures and respond to environmental challenges with improved organisational resources. Warning the population of spikes of air pollution and restricting activities, especially for the populations at higher risk, can reduce the health impacts. However, this may also require more flexibility in terms of working hours or telework initiatives, if possible, in order to avoid high impacts on the labour market. The efficiency of flexible work initiatives depends on the stage of economic development and it may be beneficial only in countries with a high share of services sectors (rather than e.g. industrial).

Human exposure to air pollution has a spatial dimension. This is because both population density and the resulting pollutant concentrations vary over space. This creates a role for both local initiatives and measures that do not take specific account of local factors, such as vehicle or industrial emission standards. Effective local policies, aiming at reducing pollution levels in highly populated areas include industrial relocation, spatially-differentiated pollution taxes and environmental and residential zoning (Cárdenas Rodríguez et al., 2015). Moreover, lower income groups are usually more exposed to pollution, as they are often located in more polluted and populated areas (where housing costs are lower). They also usually have longer commutes with exposure to high concentrations on roadways, and have (in many cases) restricted access to healthcare. Therefore, spatial considerations need to be recognised when designing air pollution control policies.

Even if air pollution mostly has local and regional consequences, it is also a global problem. Several pollutants and small particles such as PM can be transported by winds and have impacts in regions and countries other than the ones where they have been emitted. Further, air quality is deteriorated in almost all major regions of the world, and international linkages between countries, not least through international trade, mean that changes in consumption patterns in one country affect emission levels in others. The high pollution levels in China are not only a consequence of increasing domestic consumption, but also of production activities for export purposes. Global solutions are also needed to develop less polluting technologies, and a global transformation of the energy system is an essential part of any cost-effective policy response (IEA, 2016).

Many countries are actively taking steps to avoid the direst consequences of inaction of air pollution. If these policy plans are effectively implemented and followed by more ambitious policies, the costs of inaction as portrayed in this report will not materialise in full. As discussed in Chapter 2, this report does not provide a prediction of what will happen, but a plausible projection of what might happen if countries do not undertake any further efforts to reduce emissions below the levels that result from current legislation.

Further, there are strong interactions with a wide variety of other policy domains. Reducing air pollution provides an opportunity to reap synergies with investments in green growth, green technology, green infrastructure, and with promoting innovation. An overarching sustainable development framework that encompasses a country-specific sustainable development strategy and that promotes green growth, clean technologies, and less inequality and poverty would provide an integrated policy response that would include the multiple benefits of co-ordinated action. Such an integrated policy response can help exploit synergies between different policy objectives and avoid harmful contradictions between uncoordinated regulations.

There are strong interactions between air quality measures and climate or energy policies. A cleaner energy sector or the implementation of climate policies will also lead to lower emissions of air pollutants as well as higher cost-efficiency. It is therefore important to stress the need for integrated policies that consider trade-offs and co-benefits for policy objectives on climate change, energy and air pollution. Stimulating energy efficiency is the typical example of an integrated policy response that has multiple benefits (IEA, 2014).

The consequences of air pollution also have strong interactions with health care policy implementation. For instance, the improved availability and effectiveness of health infrastructure can help reduce the negative impacts on both labour productivity and the disutility of illness. With air pollution worsening in many parts of the world, there may also be more research, which will lead to a better understanding of exposure to high levels of concentrations of air pollutants and to better understanding of the burden of other diseases. The availability of this type of information will also help find responses in terms of cures and recommendations.

There is no one-fits-all recipe for reducing the impacts of air pollution. There are large differences among countries in terms of prevalent pollutants and sources. In general, a mix of policy instruments provides flexibility and wide coverage, although undue overlap between policy instruments should be avoided. Analysing the sources and causes of emissions in each country can guide towards the choice of the optimal policy mix and avoid policies in one sector harming another. A co-ordinated policy mix among different environmental issues is essential. This would avoid policy trade-offs such as achieving renewable energy targets by increasing biomass use for heating, while causing an increase in local PM pollution.

Notes

1. A death can be classified as premature if it happens before the expected age, as related to the life expectancy of a country, gender or specific health state, and if it can be prevented by reducing the cause of death, in this case outdoor air pollution.

2. Throughout this report, monetary values are presented in constant 2010 US dollars using purchasing power parity (PPP) exchange rates (i.e. "international dollars"), unless otherwise indicated. For brevity, this is indicated in the text simply as "USD".

3. The term "region" is applied loosely throughout the report; ENV-Linkages contains a combination of 12 major countries and 13 groups of countries. These are generically referred to as regions.

4. VOCs refer to a group of carbon-based chemicals (such as acetone, benzene, formaldehyde and toluene). Each and every chemical has its own toxicity and different effects on human health. In principle, methane (CH_4) is also a VOC, but it is considered separately here, so the group of VOCs referred to throughout this report excludes methane. This group of pollutants is often referred to as non-methane VOCs (NMVOCs).

5. Ozone occurs in significant quantities both as a pollutant and as a natural component of the atmosphere. At higher elevations, ozone screens out harmful ultraviolet radiation. However, close to the ground, ozone is harmful to human health, vegetation and some materials. There is a complex relationship between ozone and nitrogen oxides (NO_x); under some conditions, emissions of NO_x will lead to ozone formation, while under others they will lead to a reduction in local ozone levels.

6. Many people are exposed to both indoor and outdoor air pollution. Thus, mortality attributed to the two sources cannot simply be added together. The total estimate of WHO is around

7 million deaths in 2012. Further, the Global Burden of Disease initiative, using slightly different response functions and exposure estimates, obtains a lower figure for outdoor air pollution mortality of 3.1 million deaths per year for 2013 from exposure to PM and ozone.

7. This report also identifies a number of ways in which climate change policies may worsen indoor air pollution, not least through higher fuel prices (which may drive poor households back to traditional biomass use) and improved insulation.

8. Some literature exists that attempts to calculate the total value of specific activities and heritage sites, not least the Economics of Ecosystems and Biodiversity (TEEB) study and the UK National Ecosystem Assessment, but these cannot be used to value the associated impacts of outdoor air pollution, not least because of problems of attribution.

9. Willingness-to-pay (WTP) measures how much money (income) a person is willing to pay to avoid or reduce the risk of a negative outcome to materialise. In the current context, it aims to measure how much people are willing to pay to avoid an increase in their risk of dying prematurely or falling ill because of outdoor air pollution. WTP is often measured through stated preference methods, i.e. questionnaires where respondents indicate their WTP value.

10. The difference in methodologies for the estimation complicates the comparability of market and non-market costs.

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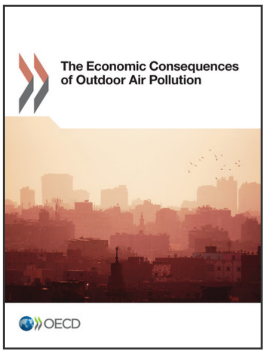

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