Annex C

Methodology to calculate the health impacts

Following the quantification of population exposure to air pollution using the TM5-FASST model, analysis of health impacts proceeds by combining information on concentration response functions, the fraction of population at risk and the incidence of ill-health, to quantify the health impacts of air pollution, including e.g. the number of cases of mortality, hospital admissions, and chronic bronchitis.

Mortality

The Global Burden of Disease (GBD) mortality results for 2010 from the work of Forouzanfar et al. (2015) and Brauer et al. (2016) for $PM_{2.5}$ impacts and Lim et al. (2012) for ozone impacts are taken as the starting point for all countries, together with annual average population-weighted exposure data at the national level for $PM_{2.5}$, and the mean of 6-month maximum concentration (M6M) for ozone. The GBD results were adopted as they were derived from a major international peer-reviewed exercise, carried out at a higher level of spatial disaggregation than was possible in this study. Given that the GBD estimates are limited to the present time and based on cause-specific analysis of mortality, it is necessary to consider the extent to which changes in health to 2060 will affect the results. An analysis of WHO data as related to UN-sourced population data carried out for this study found that observed changes in the cause of death in each region over time are not so large as to add significant uncertainty to the analysis.

For ozone, a linear model was adopted where a unit change in M6M generated the same change in risk throughout the concentration range generated for the study in excess of a counterfactual concentration adopted by Lim et al. (2012). Changes in projected mortality rates for future years were also factored into the analysis using data from the UN's World Population Projections (UN, 2012).

GBD has adopted a non-linear response function for quantification of the effects of $PM_{2.5}$, an approximation of which has been implemented here. The non-linearity in the curve is intended to account for an expected decline in response per unit of exposure as concentrations rise. Noting uncertainty in the development of this function (there is little information available to inform the shape of the relationship at high ambient concentrations typical of those in countries like the People's Republic of China and India where the majority of impacts are expected to occur), a linear function has also been derived for $PM_{2.5}$ for the present study. For the non-linear relationships, the mortality estimates for $PM_{2.5}$ from GBD were analysed to parameterise the following equations, generating individual estimates of α and β for each country:

$$PAF_{GBD} = \begin{cases} \alpha \ln(concentration\ in\ \mu g/m^3) + \beta, & for\ concentrations > 5.8\ \mu g/m^3 \\ 0, & otherwise \end{cases}$$

Where *PAF* = pollution attributable fraction, and *α* and *β* are curve-fitting coefficients to the GBD results. Impacts on mortality are therefore measured against a reference level of pollution (5.8 mg/m³) below which it is assumed that the impacts of outdoor air pollution on health do not lead to any premature deaths. The value 5.8 μg/m³ is a counterfactual or "cut-off" concentration below which no additional health impacts are calculated. It is not a health risk threshold, as emerging epidemiological evidence finds adverse health burdens for even lower concentrations (e.g. Shi et al., 2016).

The number of premature deaths is then calculated based on the *PAF*, following this equation:

$$Deaths = PAF_{GBD} \times CMR \times Population$$

Where *CMR* = crude mortality rate. CMR is taken from the World Bank's World Development Indicators (World Bank, 2015) for 2010, and the UN's World Population Prospects (UN, 2012) for subsequent years under the median fertility projection. For year 2010, the deaths calculated with the specified equation match the number of deaths calculated by the GBD study.

The alternative linearised model for quantifying $PM_{2.5}$ impacts on mortality was derived in a similar way to the model used for ozone, again accounting for changes in mortality rates in future years. Together these relationships provide a range for mortality impacts with the non-linear function providing the lower projection and the linear function the upper projection.

Morbidity

For analysis of morbidity (illness) impacts, the analysis is based on the conclusions of the HRAPIE (Health Response to Air Pollutants in Europe) study (WHO, 2013), which was used in the cost-benefit analysis of the European Commission's Clean Air Policy Package of December 2013 (Holland, 2014; European Commission, 2013). It is acknowledged that other groups have developed or applied alternative sets of response functions for morbidity, including USEPA (2011, for the prospective analysis of the benefits of the US Clean Air Act to 2020). The HRAPIE conclusions were adopted here because the study, led by WHO, is both recent and involved experts from a large number of countries in both Europe and North America. The effects quantified using the HRAPIE functions were as follows:

- $PM_{2.5}$
  - Effects of chronic (long term) exposure on adult and childhood bronchitis;
  - Effects of acute (short-term) exposure on hospital admissions for respiratory and cardiovascular illness, restricted activity days, lost working days, asthma symptom days for children;
- Ozone
  - Effects of acute (short-term) exposure on hospital admissions and "minor" restricted activity days.

Bronchitis takes a different course for adults and children. For adults, the disease, once initiated, is long lasting, often persisting until death, and varying in severity from minor to severe. For children, however, the disease is short-lived, lasting for about 2 weeks on average. These differences are reflected in the economic valuation. Although there are more cases of childhood bronchitis, the longer lasting cases of adult bronchitis generate larger economic damage.

Quantification of these morbidity effects requires knowledge of incidence rates across the population. Whilst these data are available for a growing number of countries they are not available for all. This problem has been identified in previous work carried out for OECD on transport (OECD, 2014), with morbidity costs quantified as a fixed proportion of mortality costs, 10%, referenced against cost-benefit analyses for the European Commission and US-EPA. An advantage of this approach is that it automatically factors in the question of non-linearity in response functions in a manner that it is consistent with the approach taken for mortality.

To provide analysis for all countries it is therefore necessary to extrapolate results. The approach taken here is broadly similar to that used in OECD (2014) but more detailed. Results from the analysis of the European Commission's Clean Air Policy Package, for which the HRAPIE functions had been applied in full, were adopted as the basis for this extrapolation. It was assumed that there would be a linear relationship between mortality and morbidity. In theory, higher rates of mortality might reduce the population at risk of bronchitis and other illnesses. The position taken here assumes that air pollution related mortality does not significantly affect the population at risk as exposure levels rise. Using results from Holland (2014) averaged ratios between mortality and morbidity across 28 countries from the European results were obtained. These were then adjusted to account for differences in mortality estimates for European countries between Holland (2014) and GBD.

For ozone, a single estimate was made for each morbidity effect, whilst for $PM_{2.5}$, two estimates, linked to the linear (upper projection) and non-linear (lower projection) mortality functions were derived for all years after 2010. Results for 2060 are shown in Table C.1. Chapters 4 and 5 illustrate results only relative to the upper estimates (which for 2060 are roughly 50% greater than the lower projections). Preference for the upper projection for morbidity can be justified from the perspective that only a subset of possible impacts can be quantified at the present time (RCP, 2016, provides a commentary on the variety of impacts that can be linked to air pollution over the life course).

Table C.1. **Range of health impacts at global level for 2060**

Respiratory diseases (million number of cases)	
Bronchitis in children aged 6 to 12	24-36
Chronic bronchitis (adults, cases)	7-10
Asthma symptom days (million number of days)	
Asthma symptom days (children aged 5 to 19)	230-360
Healthcare costs (million number of admissions)	
Hospital admissions	8-11
Restricted activity days (million number of days)	
Lost working days	2 460-3 750
Restricted activity days	9 820-14 900
Minor restricted activity days (asthma symptom days)	2 580

It is acknowledged that the extrapolation of morbidity results for Europe to the rest of the world is subject to a number of uncertainties, most importantly that:

- Due to lack of data, it assumes similar prevalence rates for each disease throughout the world to those seen in European countries, when these will of course vary substantially. It does not recognise variation in rates of specific diseases in the same way that the GBD analysis does for cause-specific mortality.
- It implicitly assumes that healthcare provision is similar in all countries, when it patently is not. Hence for hospital admissions, it implies that European admission rates are typical of all other countries, when there is substantial variation around the world with respect to access to healthcare systems. The problem is most serious for extrapolation for developing countries as this is where the majority of impacts are expected to occur. Most of these countries will have a lower level of healthcare provision than is typical of European countries. Against this, however, the lack of healthcare facilities clearly does not mean that everyone is well. People will still experience the illness. Indeed, it may become significantly worse through the lack of healthcare, with the result that the impact is more severe than it would otherwise be. Thus, while this assumption may imply an overestimation of health expenditures, it underestimates welfare costs.
- A similar issue arises with respect to lost working days. The European results are based on European rates of absenteeism, with a certain standard of social welfare and employment conditions that is not universal. Employees without these conditions may be inclined to go to work when they would otherwise be considered unwell ("presenteeism"), and may take longer to recover (or alternatively, develop worse illness), and therefore also have lower labour productivity.

Valuation

The approach to valuation is described in Chapter 2, with the unit values used for analysis shown in Table 2.2. These values are adjusted to account for economic conditions in each country, and the development of the economies over time.

Three elements are considered for morbidity valuation, healthcare costs, lost productivity, and welfare losses through pain, suffering, etc. There is some potential in doing this for double counting of costs, for example, if willingness-to-pay estimates account implicitly for lost productivity and healthcare costs. However, Table C.2 demonstrates that such potential double-counting has been avoided largely by attributing endpoints to a specific cost component.

Table C.2. **Cost components to the valuation of health endpoint**

	Welfare cost	Healthcare cost	Productivity cost
Deaths	100%	0%	0%
Chronic bronchitis (adults, cases)	82%	18%	0%
Bronchitis in children aged 6 to 12	92%	8%	0%
Equivalent hospital admissions	14%	86%	0%
Restricted activity days (all ages)	100%	0%	0%
Minor restricted activity days (children 5-19 yr)	100%	0%	0%
Lost working days	0%	0%	100%

Only three impacts (bronchitis in adults, bronchitis in children, equivalent hospital admissions) are assessed under more than one of the categories applied. All three effects combine welfare cost with healthcare cost, and in each case, one of the value categories dominates with more than 80% of total value (hence the maximum extent of any double counting for these effects is of the order of 25%). In selecting the welfare valuation data the main sources used have been European, reducing the probability that respondents would have included healthcare costs in their response given typical European models for funding healthcare. Combined with the view (RCP, 2016) that there are a number of impacts that could be added to the analysis, it is concluded that double counting of health related costs is insignificant to the analysis.

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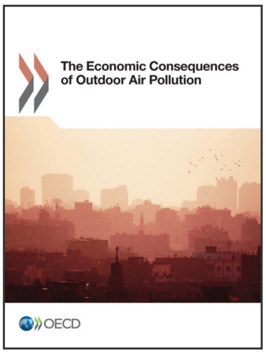

From:
The Economic Consequences of Outdoor Air Pollution

Access the complete publication at:
https://doi.org/10.1787/9789264257474-en

Please cite this chapter as:

OECD (2016), “Methodology to calculate the health impacts”, in *The Economic Consequences of Outdoor Air Pollution*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/9789264257474-11-en