Chapter 5

Welfare costs of outdoor air pollution to 2060

This chapter presents the results of the analysis of the welfare costs of outdoor air pollution. It starts with an assessment of welfare costs related to the non-market impacts, including both mortality and morbidity, namely those related to the disutility caused by illness. The chapter ends with a discussion of the possibility to compare and add market and non-market costs when they are both expressed as welfare costs. While non-market costs are evaluated through the results of willingness-to-pay studies, market costs are calculated with the ENV-Linkages model and expressed in welfare terms using equivalent variation of income.

5.1. Welfare costs of mortality

As discussed in Chapter 3, air pollution is already the cause of a large number of premature deaths, and pollution-related mortality is projected to increase in the coming decades unless more stringent policies are adopted. It is possible to attribute a cost to these premature deaths with estimates of willingness-to-pay (WTP) based on stated preference (SP) studies. In particular, this report presents the welfare costs of the premature deaths caused by air pollution, calculated using the VSL (see Section 2.6 for an overview of the VSL methodology used).

Table 5.1. **Welfare costs from mortality due to outdoor air pollution, central projection**
Billions of USD, 2010 PPP exchange rates

		2015	2030		2060	
			Non-linear	Linear	Non-linear	Linear
OECD America	Canada	20	30	30	60	60
	Chile	10	10	10	20	20
	Mexico	30	60	60	230	230
	USA	380	460	490	790	830
OECD Europe	EU large 4	360	400	400	500	540
	Other OECD EU	230	310	300	490	490
	Other OECD	140	260	250	670	660
OECD Pacific	Aus. & New Z.	0	10	10	10	20
	Japan	190	270	260	390	400
	Korea	60	130	120	280	290
Rest of Europe & Asia	China	850	2 260	2 450	6 730	8 830
	Non-OECD EU	30	40	40	70	70
	Russia	160	240	240	300	300
	Caspian region	60	150	150	540	560
	Other Europe	30	40	40	90	90
Latin America	Brazil	40	80	80	200	200
	Other Lat. Am.	40	70	80	270	270
Middle East & North Africa	Middle East	80	180	190	770	910
	North Africa	30	60	60	260	270
South and South-East Asia	ASEAN 9	60	140	140	640	750
	Indonesia	30	60	60	230	240
	India	220	570	670	3 360	7 260
	Other Asia	70	150	140	1 070	1 700
Sub-Saharan Africa	South Africa	10	20	20	40	40
	Other Africa	30	50	50	290	300
	World	*3 160*	*6 050*	*6 340*	*18 300*	*25 330*
	OECD	*1 420*	*1 940*	*1 930*	*3 440*	*3 540*
	Non-OECD	*1 740*	*4 110*	*4 410*	*14 860*	*21 790*

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Note: Due to the curvature of the functions and rounding, the effects of the non-linear projection can in some cases be reported to be slightly higher than the linear projection; this only affects the results for low and modest concentration levels.

Table 5.1 presents results on the welfare costs associated with the premature deaths caused by outdoor air pollution, relative to both $PM_{2.5}$ and ozone. To facilitate comparison with the modelling results presented in Chapter 4, the national calculations are aggregated into the regional grouping used in the modelling framework. The costs at global level are projected to be close to USD 3.2 trillion in 2015 and increase to USD 18-25 trillion in 2060 (using constant 2010 PPP exchange rates) according to the two different estimates of the number of premature deaths calculated (respectively with linear and non-linear concentration-response function). That is a six- to eightfold increase, which is driven by the increasing number of premature deaths at global level (caused by changes in demographic and concentration trends) and by increasing VSL (following income growth especially in emerging and developing countries).

Welfare costs from premature deaths are by 2060 projected to more than double in OECD countries, going from USD 1.4 trillion in 2015 to USD 3.4-3.5 trillion in 2060. Nevertheless, a larger increase and share of costs are estimated to be in non-OECD economies, where they amount to almost USD 1.7 trillion in 2015 and are projected to increase roughly tenfold to reach USD 15-22 trillion in 2060. That is mostly due to the high number and increase in premature deaths in the People's Republic of China (henceforth "China") and India.

Despite the differences in methodologies, these numbers are comparable to the ones in OECD (2014). OECD (2014) estimates that air pollution caused nearly 500 thousand premature deaths in 2010, corresponding to a welfare cost of USD 1.5 trillion. This report uses the same VSL for OECD countries.

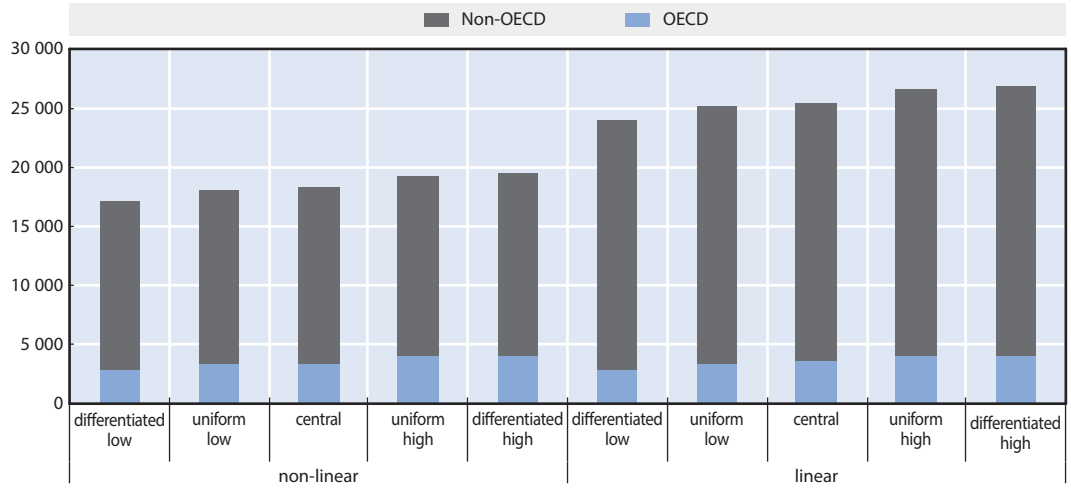
As discussed in Section 2.6, the VSL values used in this report are calculated using a reference OECD value of 2005 USD 3 million and then using benefit transfer techniques to calculate country-specific values following OECD (2012). This is done on the basis of country-specific income and with an income elasticity of 0.8 for high-income countries, 0.9 for middle-income countries and 1 for low-income countries. While this reflects the most reliable values according to the recent literature, there is still a high level of uncertainty surrounding these values.

Figure 5.1 presents a sensitivity analysis on the valuation of premature deaths according to four alternative assumptions on the income elasticities used: *(i)* a uniformly high level, with an elasticity of 1 for all regions; *(ii)* a uniformly low level, with an income elasticity of 0.8 for all regions; *(iii)* a differentiated high level, with 1 for high-income countries, 1.1 for middle-income countries and 1.2 for low-income countries; and *(iv)* a differentiated low level, with 0.6 for high-income countries, 0.7 for middle-income countries and 0.8 for low-income countries.

The figure clearly shows that the uncertainty on the number of deaths (linear versus non-linear) matters more for the assessment of the welfare costs in 2060 than the income elasticity that is used for calculating future values per premature death. The uncertainties are somewhat larger for developing and emerging economies, especially China, than for OECD countries. Including the uncertainty on the valuation broadens the global range of welfare costs from mortality from USD 18.3-25.3 trillion (central projection) to USD 17.2-26.8 trillion. Effectively, at the global level the uncertainty on the valuation increases the uncertainty range of USD 1-1.5 trillion on each side of the range. More than half of that can be attributed to the uncertainty on the values for China. For OECD countries, the uncertainty on the number of deaths tends to be relatively small (cf. Figure 3.8), and the choice of income elasticity matters more. In contrast, for India the uncertainty on the number of deaths is much more important than the uncertainty on the valuation.

Figure 5.1. **Sensitivity of welfare costs from premature deaths to the income elasticity**

Billions of USD, 2010 PPP exchange rates, 2060



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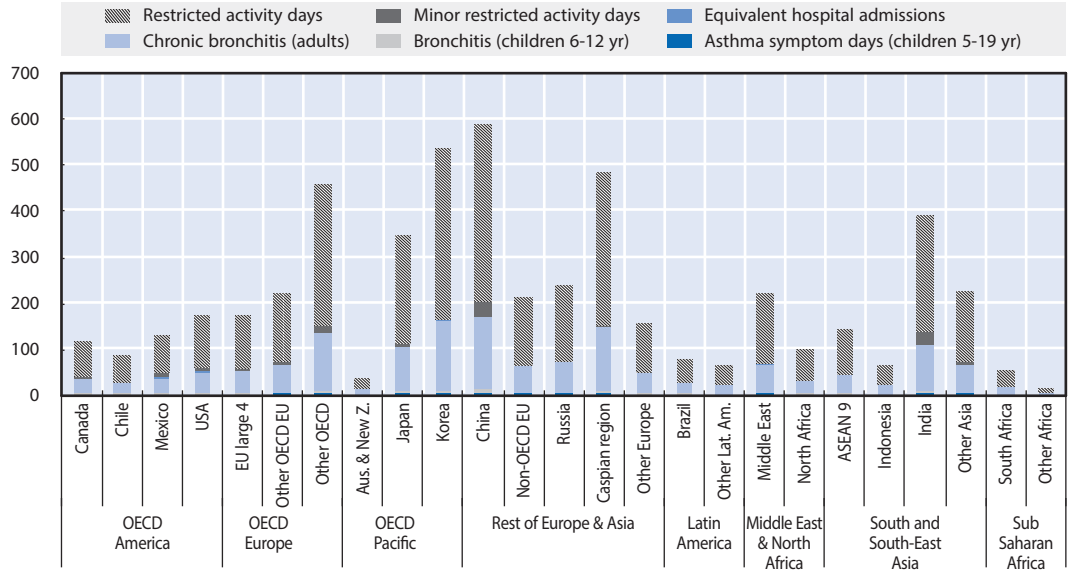
5.2. Welfare costs of morbidity

In this report, the costs related to the disutility of illness are considered to be non-market costs and are estimated using WTP from SP studies, as explained in Section 2.6. Figure 5.2 illustrates the per-capita welfare costs from illness, as broken down into different categories: the costs relative to restricted activity (both restricted and minor restricted activity days), hospital admissions, and illness (new cases of chronic bronchitis in adults, bronchitis in children aged 6 to 12 and asthma symptom days for children aged 5 to 19).

Figure 5.2. **Welfare costs from illness due to outdoor air pollution, central projection**

USD per capita, 2010 PPP exchange rates, 2060



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The largest welfare costs come from the restricted activity days, which cause disruptions of normal activities, followed by chronic bronchitis in adults. The regions with the highest per capital costs are China, followed by Korea, Eastern Europe and the Caspian region. These are regions in which the number of cases of illness per capita is highest. Interestingly, Korea and China have similar results, especially for chronic bronchitis in adults. The projected number of cases of chronic bronchitis is higher in China than in Korea (almost 3 million cases in China and 260 thousand cases in Korea in 2060). However, when calculating per capita costs the size of the population matters and it is much higher in China. Further, the value attributed to a single case of adult bronchitis is lower in China than in Korea.

At the global level, welfare costs from non-market impacts of morbidity are estimated to be USD 280 billion in 2015 and USD 2.2 trillion in 2060. This sharp increase over the coming decades shows that an increasing number of people will be affected by air pollution with disruptions to daily life and increasing costs from illness.

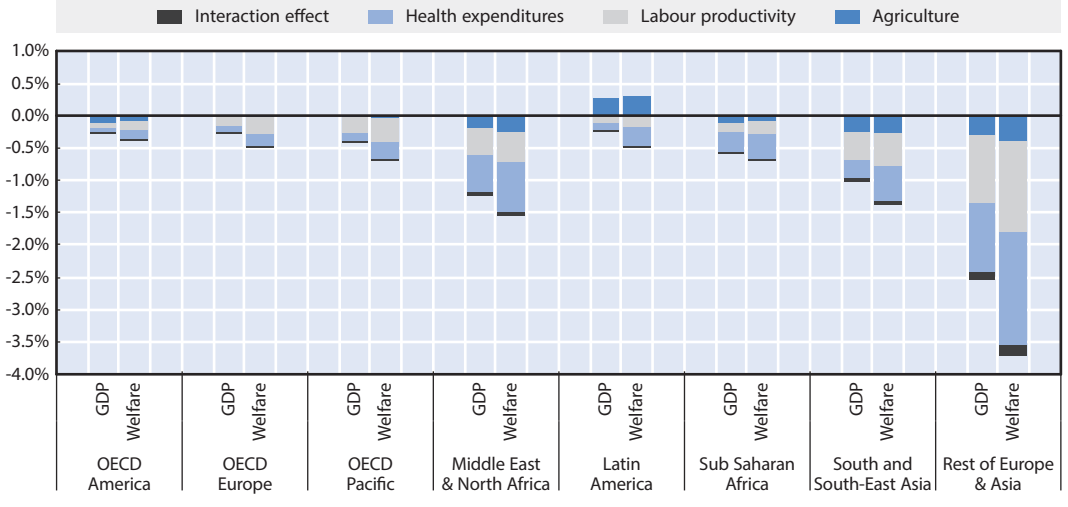
5.3. Welfare costs of market impacts

In this report, market costs of health impacts are associated with the effects of the additional health expenditures and changes in labour productivity, as calculated in the general equilibrium model.[1] In addition to these costs, the modelling framework is used to calculate costs of agricultural impacts, plus the indirect costs and effects that take place in the economy, such as sectoral adjustments.

The costs relative to the selected market impacts of air pollution have been presented in Chapter 4 as percentage of GDP. However, GDP cannot directly be compared to the welfare costs of mortality and morbidity presented in Sections 5.1 and 5.2 respectively. Using equivalent variation of income, it is possible to calculate the private welfare costs of the selected impacts of air pollution (excluding welfare losses from the reduced provision of public goods). For more discussion on calculating welfare costs in a computable general equilibrium (CGE) framework, see Section 2.8. GDP and the welfare costs of market impacts are presented in Figure 5.3 as the combined effects of health expenditures, labour productivity, agriculture and an interaction effect.

Figure 5.3. **GDP and welfare costs of market impacts of outdoor air pollution, central projection**

Percentage change of GDP and income w.r.t. no-feedback projection, 2060



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Source: ENV-Linkages model.

The welfare costs are generally larger in percentage change than the GDP impacts: the global cost of air pollution in 2060 is 1.0% of GDP, and 1.5 % of income as calculated with the equivalent variation of income. For agriculture, the equivalent variation is similar to GDP, while for labour productivity and especially health expenditures, welfare costs are larger. The largest difference is for health expenditure, which is the only impact on the demand side. This suggests that impacts on the demand side, which affect private welfare directly, are much larger when considering welfare than when using GDP. The logic for this result is that demand shocks directly affect consumption. The effect of that on welfare cost is corresponding, while it is muted in the change in GDP, which fails to capture the welfare implications of the shocks.

5.4. Bringing together market and non-market costs

Comparing welfare costs from market and non-market impacts

The market costs calculated in the general equilibrium model and expressed in terms of welfare can be compared with the valuation of the non-market welfare costs from premature deaths and disutility from illness. Unfortunately, there is insufficient information to provide an uncertainty range for the costs presented in this section. Only the range for the projected number of premature deaths is included. Therefore, the absolute numbers presented should be treated only as indicative of the order of magnitude of the results, and do not reflect accurate estimates of the welfare costs of outdoor air pollution in the different periods.

Table 5.2 presents the various types of annual welfare costs of air pollution: *(i)* the direct and indirect welfare costs of the selected market impacts of morbidity and agricultural impacts (cf. Section 5.3); *(ii)* the disutility costs from illness (cf. Section 5.2); and *(iii)* the premature deaths due to air pollution (cf. Section 5.1).

The annual welfare costs of the different market impacts in the OECD add up to USD 90 billion in 2015, USD 150 billion by 2030, and USD 390 billion by 2060. That reflects 0.3%, 0.3% and 0.5% of income (as measured in GDP per capita), respectively; or USD 70, USD 110 and USD 270 per capita. At the global level, the numbers are larger, both in absolute terms and as percentage of income, and rising much more rapidly over time: while in 2015 and 2030 the average welfare costs of the market impacts per person are lower in non-OECD economies than in the OECD region, by 2060 they are substantially higher in non-OECD economies, reaching 1.5% of income.

For the OECD as a whole, the annual welfare costs related to non-market health impacts of outdoor air pollution amount to up to USD 1.6 trillion by 2015, and rise to USD 3.9 trillion in 2060, of which more than 90% stem from the welfare loss of premature deaths. At the global level, the costs are projected to be USD 3.4 billion in 2015 and are rising more rapidly, reaching USD 6.6-6.9 trillion by 2030, and USD 20.5-27.6 trillion by 2060. This larger uncertainty band reflects the sensitivity of the projected premature deaths at very high concentration levels, where the concentration-response function potentially becomes non-linear (see Section 5.1).

These welfare costs from non-market impacts are not related to expenditures or tradable goods; they can therefore not be directly compared with macroeconomic indicators such as GDP. But to give a sense of the order of magnitude of these welfare costs, one can express them as a share of total income; for the OECD countries combined this is around 5% in 2015, and remain roughly constant over time. At the global level, they increase from 6% in 2015 to 9-12% in 2060.

Table 5.2. **Total welfare costs of outdoor air pollution, central projection**

Billions of USD, 2010 PPP exchange rates

	OECD			World		
	2015	2030	2060	2015	2030	2060
Welfare costs from market impacts						
Agriculture						
Direct costs	10	10	20	40	50	80
Indirect economic effects	10	20	40	50	90	320
Health: Morbidity						
Health expenditures						
Direct costs	10	10	30	20	40	140
Indirect economic effects	20	40	100	120	290	1 350
Labour productivity						
Direct costs	30	40	60	50	90	350
Indirect economic effects	10	30	120	30	140	900
Economic interaction effects	0	0	20	20	30	160
TOTAL market impacts	**90**	**150**	**390**	**330**	**730**	**3 300**
Share of income (percentage)	*0.3%*	*0.3%*	*0.5%*	*0.6%*	*0.7%*	*1.5%*
Per capita (USD per capita)	*70*	*110*	*270*	*50*	*90*	*330*
Welfare costs from non-market impacts						
Health						
Morbidity: Disutility costs	130	170	310	280	560	2 240
Mortality	1 420	1 930-1 940	3 440-3 540	3 160	6 050-6 340	18 300-25 330
TOTAL non-market impacts	**1 550**	**2 100-2 110**	**3 750-3 850**	**3 440**	**6 610-6 900**	**20 540-27 570**
*Share of income (percentage)**	*5%*	*4%*	*5%*	*6%*	*7%*	*9-12%*
Per capita (USD per capita)	*1 210*	*1 530-1 540*	*2 610-2 680*	*470*	*780-820*	*2 060-2 770*
Other costs						
Missing effects (biodiversity, cultural heritage, …)	N/A	N/A	N/A	N/A	N/A	N/A

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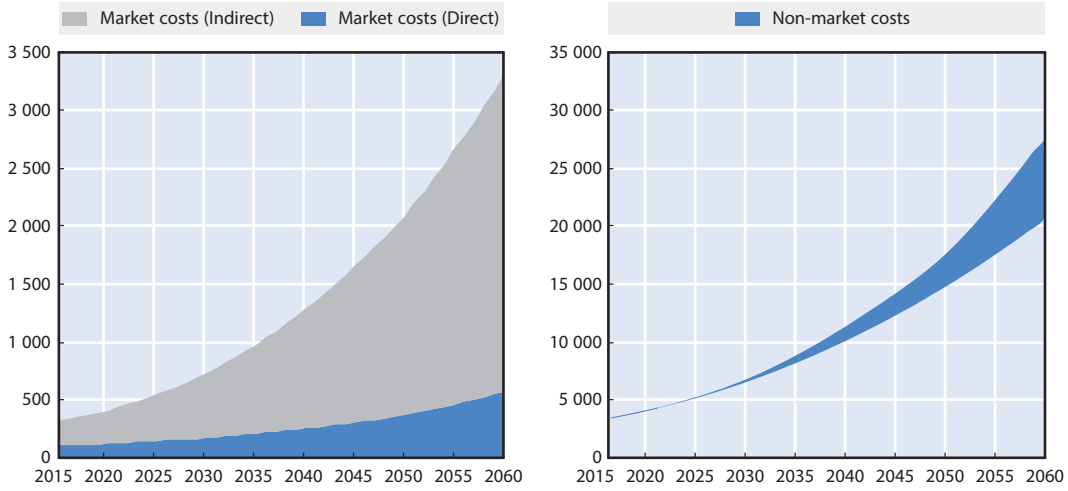
* Welfare costs from non-market impacts are not related to expenditures and therefore not an integral part of the calculation of income; the expression of these welfare costs as share of income is therefore only for illustrative purposes.

Finally, one can represent these non-market welfare costs also in per capita terms. In 2015, the per-capita welfare costs of outdoor air pollution for non-market impacts are higher in OECD countries than in the emerging and developing countries: around USD 1 200 per capita for the OECD, and less than USD 500 per capita for the world. By 2060, the situation is changed, despite continued population growth in developing countries: per capita costs in the OECD region are projected to rise modestly to USD 2 610-2 680, whereas they increase to USD 2 060-2 770 globally. A large share of increasing non-OECD costs takes place in the Rest of Europe and Asia region (incl. China), as previously discussed. This reflects both the high concentration levels and the increase in costs associated to the health impacts that follows economic growth and rising income levels.

While it is clear that by far the largest cost component is the welfare loss from premature deaths, indirect economic consequences as induced by the various market impacts have an increasingly important role. When using welfare as a measure for the market costs, indirect economic effects are calculated as the difference between direct market costs and the equivalent variation of income.

In the short- and medium term, indirect economic repercussions tend to be of the same order of magnitude as the direct market impacts. But in the long run (2060), the induced economic consequences of air pollution will outweigh the direct effects of the various market impacts, not least due to the long-term consequences of a slowdown of economic growth. Ignoring these indirect economic consequences can lead to a significant miscalculation of the morbidity costs of air pollution. Figure 5.4 confirms the increasing importance of the indirect economic consequences over time.

Figure 5.4. **Evolution of the welfare costs of outdoor air pollution over time, central projection**
Billions of USD, 2010 PPP exchange rates



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Aggregating welfare costs from market and non-market impacts

The total welfare costs of the impacts of outdoor air pollution comprise both market and non-market costs. In principle, market and non-market costs should be added up, as each part only paints a partial picture of the total welfare costs. However, this is rarely done in the literature because studies generally have focused on only one dimension of the total welfare costs. For example, the valuation literature mostly focuses on non-market costs, and ignores indirect economic effects (Hunt et al., 2016). On the other hand, the cost-of-illness and CGE modelling literature can calculate direct and indirect economic effects, but generally cannot deal with non-market impacts (e.g. Vrontisi et al., 2016).

The advantage of the comprehensive approach taken in this report is that it provides detailed projections of both market and non-market costs. Complications can arise with aggregating the two, as measurement techniques differ and as it is impossible to ensure that all possible sources of double-counting are excluded.

The welfare costs of market and non-market impacts calculated in this report are measured differently but can both be expressed as aggregate income losses. On the one hand, in the CGE modelling assessment of market costs, the equivalent variation of income reflects the maximum willingness to pay to avoid the deterioration in the economic system resulting from the market impacts of outdoor air pollution. This assessment assumes that households behave rationally and focuses purely on changes in private consumption. On the other hand, the valuation of non-market costs is based on studies directly asking respondents to value a change in risk. Relying on available estimates from the literature for non-market values implies that there is a potential that the underlying questionnaires are not fully compatible with the rest of the assessment presented in this report. This needs to be kept in mind when interpreting the aggregate results.

There is also a risk that certain costs are double counted. As explained in Section 2.6, double-counting is avoided as much as possible. Agricultural impacts are assessed only as market costs, and non-market costs are ignored.[2] Similarly, for mortality effects, double counting is excluded by focusing purely on the non-market costs, as these likely dominate and the valuation of mortality reflects total values. For morbidity effects, double counting is potentially a more significant problem because both market and non-market costs are considered, but the unit values used for disutility are based on studies that, at least in principle, cover only non-market costs and exclude all market costs (OECD, 2012).

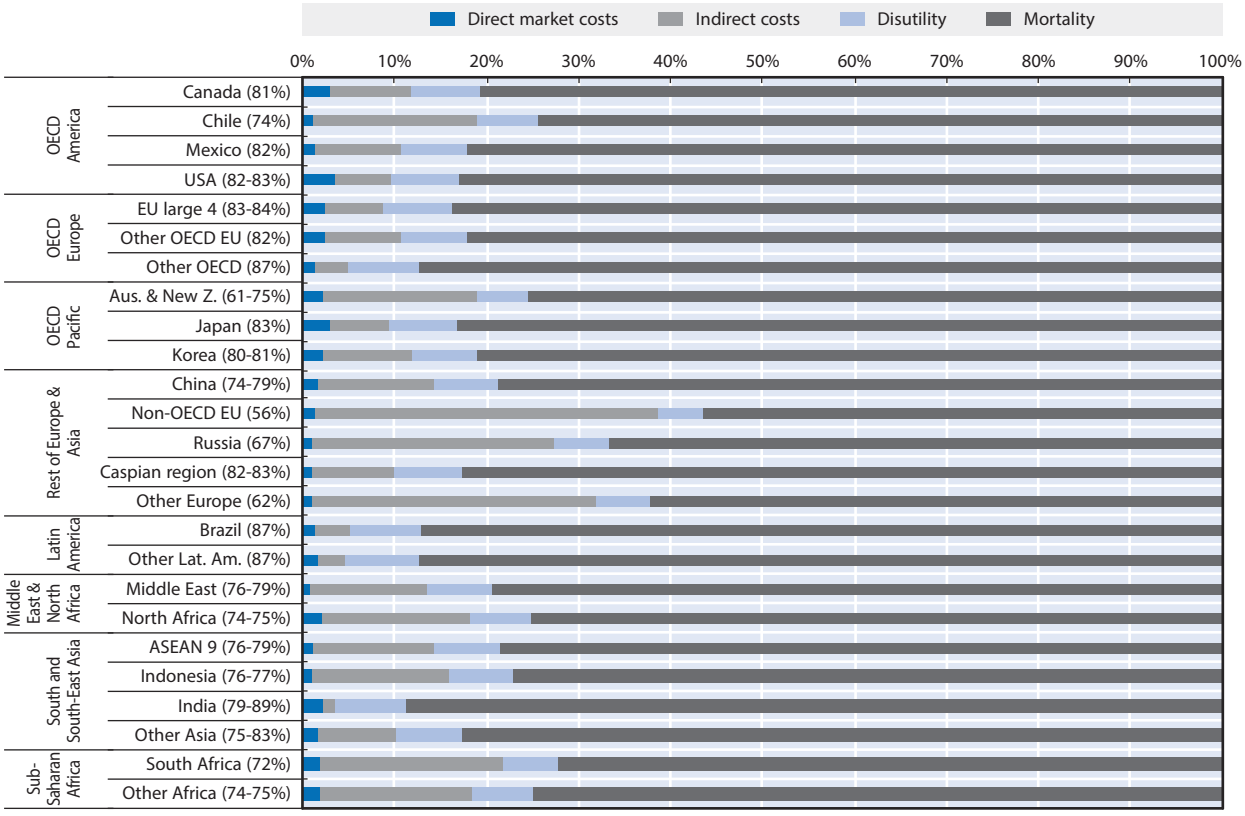
Notwithstanding these difficulties, it is legitimate to assess the full cost of inaction by summing the monetary values of the different cost components, provided the caveats are kept in mind. The uncertainties described above mean that the absolute numbers presented in this section should be interpreted with care. It is not the point estimate of the costs of inaction itself but the order of magnitude that should incentivise policy action. The numbers on the total welfare costs of outdoor air pollution presented could be seen as an upper bound of the full welfare costs related to the impacts considered given the potential for double-counting. However, these welfare costs exclude certain impacts that are likely to have negative consequences for welfare, such as the direct health effects of NO_2 or the effects on ecosystems and biodiversity, which imply that potential total welfare costs of outdoor air pollution are likely higher than those presented in this report.

Summing the different cost elements presented in Table 5.2, the total global welfare costs of outdoor air pollution from all impacts that could be measured in this report are projected to be around USD 3.8 trillion (7% of income; USD 510 per capita) in 2015, and rising to USD 23.8-30.9 trillion (11-14% of income; USD 2 400-3 100 per capita) by 2060. In comparison, the corresponding total welfare costs for the OECD region amount to USD 1.6 trillion (5% of income; USD 1 280 per capita) for 2015 and USD 4.1-4.2 trillion (5% of income; USD 2 880-2 950 per capita) for 2060, respectively.

Regional differences are especially strong for the indirect economic effects, as Figure 5.5 illustrates (using linear values for mortality). As discussed in detail in Chapter 4, in some regions, such as Eastern Europe, the indirect effects of health expenditures are especially strong and negative, and substantially worsen the welfare consequences of air pollution. But for other regions, the indirect economic consequences are much more benign, as countries can increase their competitive position relative to their competitors. This is for example the case for Brazil and other Latin American countries in the agricultural sector. This reduces the negative economic consequences, and could potentially even lead to absolute gains in economic activity, and hence GDP and welfare.

Figure 5.5. **Components of regional welfare costs of outdoor air pollution, central projection**

Shares in total welfare costs based on linear values for mortality, 2060; numbers in brackets represent the share of mortality costs for the range of linear and non-linear values



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As the share of the indirect effects increases, total morbidity costs are projected to also grow more rapidly than the costs of mortality.[3] OECD (2014) and Hunt et al. (2016) suggest using a 10% mark-up on mortality costs as a proxy for morbidity costs, based on earlier valuation studies. The results presented in this report, with all their caveats, roughly confirm that such a ratio seems adequate for short term global assessments when the indirect economic effects are small. In fact, the ratio roughly holds globally throughout the model horizon when indirect economic effects are ignored. However, this mark-up should increase over time, as in the longer run indirect economic effects are stronger. Furthermore, a generic mark-up ignores the significant differences between regions.

These results regarding the importance of indirect effects support the need to study both market and non-market impacts for the assessment of the full costs of morbidity, and hence the full costs of outdoor air pollution. This can be done with a combination of suitable tools for different types of costs, including an economic systems model for the (indirect) market costs, and direct valuation of non-market welfare costs based on WTP from SP studies.

Notes

1. Costs related to loss of leisure time could not be captured in the modelling framework.
2. The main reason for this is that there is insufficient data at global level to adequately quantify the welfare costs of e.g. ecosystem and biodiversity losses that are associated with agricultural impacts.
3. There also other factors that help explain the lower share of mortality in the long run, including improvements in health care that may avert deaths.

References

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