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Review of the implementation of the 2022–2023 workplan: policy

Cost of inaction

Summary

The present report, prepared by the Task Force on Integrated Assessment Modelling in cooperation with the Task Force on Techno-economic Issues in accordance with item 2.1.5 of the 2022–2023 workplan for the implementation of the Convention (ECE/EB.AIR/148/Add.1), was discussed by the Working Group on Strategies and Review at its sixtieth session (Geneva, 11–14 April 2022) and forwarded to the Executive Body for consideration at its forty-second session.

The report aims to encourage ratification and implementation of the protocols to the Convention, in particular the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012, demonstrating to policymakers the comparison of the costs of inaction on air pollution – defined as the damage to health, ecosystems and economy – with the costs of taking action, defined as the costs of abatement measures.

The Executive Body is expected to endorse the document.

I. Key messages

1. In nearly half of the countries in the United Nations Economic Commission for Europe (ECE) region (26 of 56) the current monetary damage costs to health and ecosystems due to ambient air pollution corresponds to over 5 per cent of gross domestic product (GDP). In at least 6 countries, the damage is more than 10 per cent of GDP. The largest part of the damage costs consists of reduced life expectancy, followed by morbidity costs (e.g., hospital admittance, sick leave, medicine costs), and damage to ecosystems. The monetized damage is – as a percentage of GDP – higher in the Eastern than in the Western part of the ECE region. Globally, labour productivity losses (mainly via work absenteeism) due to air pollution make up approximately 5–9 per cent of the total damage costs.

2. There are societal values yet to be monetized and included in the damage cost estimates, foremost the damage to biodiversity. There are also considerable information gaps between the Eastern and Western parts of the ECE region, especially regarding valuation studies carried out by East European research groups and scenarios for future air pollution levels in Eastern Europe. Dedicated efforts are still needed to address these missing values and gaps.

3. Thanks to existing policies, monetary damage in the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) domain up to 2030 is expected to be reduced by at least 14 per cent compared to 2020. The implementation of national emission reduction obligations and current emission limit values for vehicles, installations, non-road mobile machinery and products will reduce damages. Expected damage reduction will (as a percentage of GDP) be higher in the Western part of the ECE region since this region is expected to implement stricter emission reductions.

4. Up to 21 per cent of monetary damage in the European Union-27 in 2030–2050 could be avoided by additional (not included in current legislation) policy actions targeting air pollution. Applying technically feasible measures (not entailing excessive costs) could reduce annual monetary damage by 4 per cent (compared to the baseline) in 2030–2050; further damage reduction (to 20–21 per cent) can be achieved by applying all possible air pollution measures regardless of costs (maximum technically feasible reduction (MTFR) scenario). If the MTFR scenario is combined with climate measures, the damage reduction in 2050 might reach 26 per cent. In the Eastern part of the ECE region in particular, there is significant potential for reducing monetary damage.

5. Abatement costs (costs of taking action) are significantly lower than those of inaction. Benefits tend to be higher than costs. In the European Union-27, abatement costs of available additional actions on top of current ambition levels in National Air Pollution Control Programmes (NAPCPs) are over 20 times lower than costs of avoided damage.

II. Introduction

6. Since the 1960s, economists have developed methods to monetize welfare effects of adverse ecosystem and human health effects caused by poor air quality. Although early attempts suggested that costs of reducing emissions far exceeded the benefits, it is now well established that the situation is the opposite in almost all cases. Failure to act to improve air quality is therefore imposing avoidable welfare losses. In other words, failure to take action leads to costs of inaction.

7. In preparing this report, the best available knowledge on damage costs of air pollution has been reviewed and synthesized. Based on this review and synthesis of the state-of-the-art science in this discipline, the most important messages to policymakers have been extracted. The work has been guided by the following questions:

(a) Can welfare effects of poor air quality be confidently estimated?

(b) How high are the damage costs when action is not taken on air pollution?

(c) Are these damage costs expected to go up or down in the future?

(d) How can the costs of inaction be further reduced?

(e) Will human welfare improve if more is done?

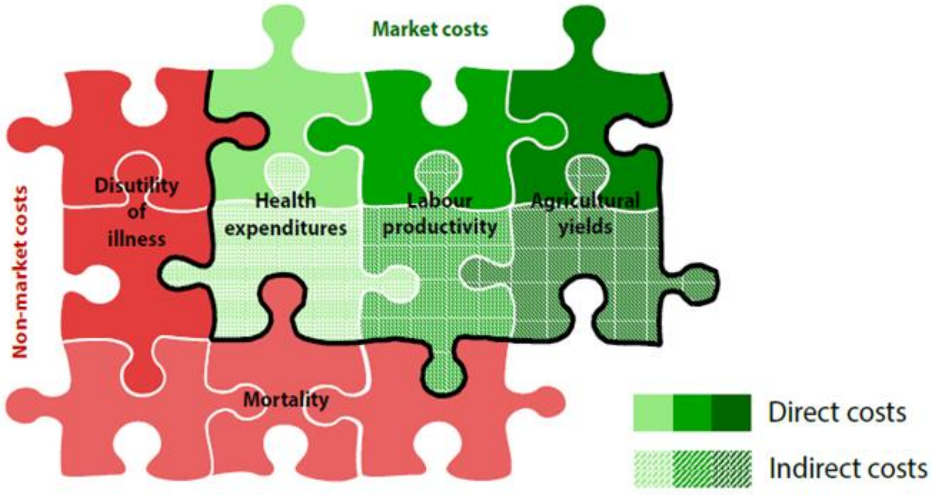
8. Included below is a conceptual overview of the costs of inaction and relevant literature. This is followed by an estimate of the current amount of damage costs from air pollution in the ECE region, the expected future reduction in damage costs, as well as available improvement potential.

III. Monetizing damages from air pollution

9. Although the exact terminology differs from one practitioner to another, in this report the following terminology was considered when writing about the economic effects of poor air quality. Welfare losses for society of poor air quality come in two main types: market costs and non-market costs (see figure 1 below).

Figure 1

Market and non-market costs of air pollution damage, split into their main categories. Figure copied from OECD, 2016.[1]



10. As examples of market costs, it has been shown that poor air quality causes productivity losses by reducing both the number of days people can go to work, as well as forest, crop and vegetable yields. Mitigating the negative effects of poor air quality consumes societal resources, such as health-care sector expenditures. All these are measurable costs that depend on current market prices, labour and health-care costs. Indirect market costs also exist; for instance, the reduction of available financial resources for investments. Requirements for market cost estimates are described in recent reports by the Organisation for Economic Co-operation and Development (OECD) (Atkinson et al., 2018;[2] OECD, 2016).[3]

11. Non-market costs occur because poor air quality reduces people’s quality of life by inducing pain, suffering and discomfort, and through premature mortality. Non-market costs are typically dominating the value of benefits in cost-benefit analyses supporting policy decisions. Non-market costs cannot be quantified in the same way as market costs. There is a range of studies setting economic values on mortality and morbidity based on individuals’ perception of the value of a change in life expectancy, risk of fatal accidents, or health status – i.e., by applying willingness-to-pay methods.

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[1] OECD, 2016. The Economic Consequences of Outdoor Air Pollution – Policy Highlights. Note that the OECD did not include (non-market) ecosystem damage in their approach.

[2] Atkinson, G. et al., 2018. Cost-Benefit Analysis and the Environment - Further Developments and Policy Use.

[3] OECD, 2016. The Economic Consequences of Outdoor Air Pollution – Technical Report http://dx.doi.org/10.1787/9789264257474-en.

12. To assess costs of premature mortality due to air pollution, two main approaches exist. One involves a valuation metric called the Value of Life Year (VOLY), another uses the Value of Statistical Life (VSL) (see box 1 below). Whether VOLY or VSL is used in a mortality cost estimate can affect the results. Therefore, the present report tries to indicate the metric used for the values presented[4] by adding "VSL" or "VOLY" after the value.

Box 1

Value of Life Year and Value of Statistical Life approaches to valuation of premature mortality caused by air pollution.

The economic values used to represent value life years and statistical life are naturally associated with uncertainties, and many parameters affect the values. Remaining life expectancy, quality of life, as well as economic resources vary over a lifetime, and all affect stated or revealed values of life-years and statistical lives. Correspondingly, results often have a wide uncertainty range.

The standard VOLY and VSL approaches to valuation of life-shortening from air pollution differ since the life years lost from air pollution typically is around 11 years (Gustafsson and others, 2018), which is lower than the halved life expectancy typically associated with VSL studies. In detail, the VOLY method is based on life tables: it takes into account at what age people die from air pollution and gives results in terms of life expectancy. The VSL method does not use life tables, instead operating with mortality rates. As the VSL method does not consider age or death reasons, it is sometimes considered to be overestimating health benefits from air pollution reduction (Desaigues and others, 2011), while the VOLY approach is more conservative. However, the VOLY approach is criticized for not valuing vulnerable populations as high as average populations.

Operationally in most impact assessments, the effect of air pollution on life expectancy or mortality is calculated through a fixed percentage change on a baseline life expectancy or relative risk. An outcome of this method is that in countries with short baseline life expectancy, air pollution affects more life years. The difference between mortality valuation with the VSL and VOLY approach will be higher in countries with long life expectancy.

Sources: B. Desaigues and others, "Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY)", *Ecological Indicators*, vol. 11, No. 3 (May 2011), pp. 902–910; Malin Gustafsson and others, *Quantification of population exposure to* NO_2, $PM_{2.5}$ *and* PM_{10} *and estimated health impacts*, IVL Swedish Environmental Research Institute, report No. C317, June 2018.

13. In this report, the term "damage costs" or "damage" refers to the sum of all the above-mentioned cost types and categories.

IV. Data, method, sources

14. Most of the data to this report are found in articles and reports published in the last 10 years. Some of the results in the report (tables 1–3) can be used for country-specific damage estimates directly. Others (e.g., figures 6–7 and 12) are deemed to be illustrative examples and can be used for comparison with countries' own estimates. Additionally, supplementary analysis of region-specific health damage has been conducted utilizing the Greenhouse Gas and Air Pollution Interaction and Synergies (GAINS) and Alpha RiskPoll models.

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[4] Where both options were available, this report presents the numbers in Value of Statistical Life (VSL) – i.e., when presenting the results of the calculations based on M. Amann and others, 2020, *Support to the development of the Second Clean Air Outlook — Specific Contract 6 under Framework Contract ENV. C.3/FRA/2017/0012 (Final Report)* (Brussels, European Commission, 2020). ()VSL was chosen since this metric allows for equal valuation of lives of people with different health status. VSL was also used in the OECD reports referred to in this report. The authors of the present report are aware that the European Commission more often uses VOLY in its assessments and policy suggestions.

A. Modelling made in this report as input into the data synthesis

15. In 2020, the International Institute for Applied System Analysis (IIASA) published scenarios for the second Clean Air Outlook[5] exploring different future air quality levels of ambitions regarding air pollution and climate measures in the European Union-27. The underlying baseline GAINS scenario (CAO2_Baseline_2030) reflects current and projected development in the entire GAINS modelling domain. To estimate current and projected health damage in the selected regions, including countries outside the European Union-27 (described below), the GAINS model outputs (population-weighted concentrations of fine particulate matter of less than 2.5 microns in diameter ($PM_{2.5}$) and Sum of Ozone Means Over 35 ppb (SOMO35) in the receptor countries) have been used as inputs into the Alpha RiskPoll model where the corresponding damage from $PM_{2.5}$ and ozone are calculated and aggregated by region. Damage assessments are done for 2020 (current situation) and 2030 (projection). The calculations are done before the invasion of Ukraine by the Russian Federation in February 2022, which has not been considered in the GAINS scenarios used for this report.

B. Regionalization

16. The monetized damage from air pollution to human health and ecosystems in this report is summarized and analysed separately for each of the following subregions of the ECE region:

(a) EECCA: Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan;

(b) South-Eastern Europe: Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, Serbia, Türkiye;

(c) Western and Central Europe: European Union-27, Iceland, Norway, Switzerland, United Kingdom of Great Britain and Northern Ireland;

(d) North America: Canada, United States of America.

C. Currency recalculations and value transfer

17. All monetary estimates are presented in year 2015 euros unless otherwise indicated. When translating literature values of non-market (intangible) health damages into year 2015 euros, this report adjusts original values by adjusting for inflation, change in GDP per capita adjusted for Purchasing Power Parity, and a VSL income elasticity of 0.8 (recommended in OECD, 2012).[6] For technical costs and damage costs constituted mainly of market-based costs (e.g., crop damage costs, labour productivity cost assessments), values are recalculated to year 2015 euros considering CPI only.

18. In the damage estimates based on GAINS and Alpha RiskPoll made, valuation of health effects is made with the same approach as above and in Amann and others, 2020.[5] Then, depending on the type of results presented, one of two spatial value transfer methods is chosen:

(a) When assessing damage as a percentage of a country’s GDP: Country-specific damage is adjusted with the income difference between the country and the European Union-27. An income elasticity of 0.8 is assumed if the country has average income higher than the European Union average, and elasticity of 1.2 if the country has lower average income.[7] The adjusted values are compared with PPP-adjusted GDP;

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[5] Amann, M. et al., 2020. Support to the development of the Second Clean Air Outlook.

[6] OECD 2012. Mortality Risk Valuation in Environment, Health and Transport Policies, OECD Publishing. http://dx.doi.org/10.1787/9789264130807-en.

[7] A VSL income elasticity of 1.2 is recommended for lower- and middle-income countries and an elasticity of 0.8 for higher income countries (Narain, U., Sall, C. 2016. Methodology for valuing the health impacts of air pollution – Discussion of challenges and proposed solutions).

(b) When presenting the absolute damage numbers per region (EECCA/South-Eastern Europe/Western and Central Europe) in year 2015 euros: the damage is adjusted with the income difference between the ECE (Europe) region and the European Union-27, applying an income elasticity of 1.2.

19. The market costs related to morbidity are estimated with other methods than willingness-to-pay, so the valuation approach in this report leads to a minor underestimation of cost of inaction (COI).

20. The estimates in the present report of the damage as a percentage of a country's GDP are done for the year 2020 (2010 for some countries of the Caucasus and Central Asia). These values should not be confused with values referred to as "per cent of GDP change" adopted from a recent OECD study[1] which present percentages of GDP in 2060 compared to the baseline scenario.

21. GDP PPP, GDP per capita PPP and population data were downloaded from the World Bank database.[8] CPI was obtained from the OECD database.[9] Currency exchange rates were taken from the European Central Bank website.[10]

V. How large is the monetized damage from air pollution to human health and ecosystems?

22. The first question answered in this overview relates to the total size of the damage costs and is presented for the EECCA, South-Eastern Europe, Western and Central Europe, North America and Global regions. EECCA is split between the countries within the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP)[11] domain[12] and the countries outside that domain.

23. Country-specific damages from air pollution depend on factors such as population density, age structure and health, current state of crops and forests, proximity to neighbouring countries and weather conditions affecting transboundary pollution.

A. Countries of Eastern Europe, the Caucasus and Central Asia

Total damage and per cent of gross domestic product

24. Total health damage from air pollution in the EECCA countries within the EMEP domain shows a descending trend (see figure 2 below, left-hand panel). Damage is expected to fall by €17.5 billion (4 per cent) between 2020 and 2030. Still, annual damage will account to €425 billion in 2030. Damage from air pollution for countries with national borders within the EMEP domain corresponds to 5–7 per cent of the countries' GDP (see figure 2, right-hand panel). For the Russian Federation, damage is only assessed for the European part of the country. Compared to the entire country's GDP, damages constitute 6 per cent; however, this value does not account for health damage to the 25 per cent of the country's population living east of the Ural Mountains.

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[8] https://data.worldbank.org/indicator.

[9] https://stats.oecd.org/#.

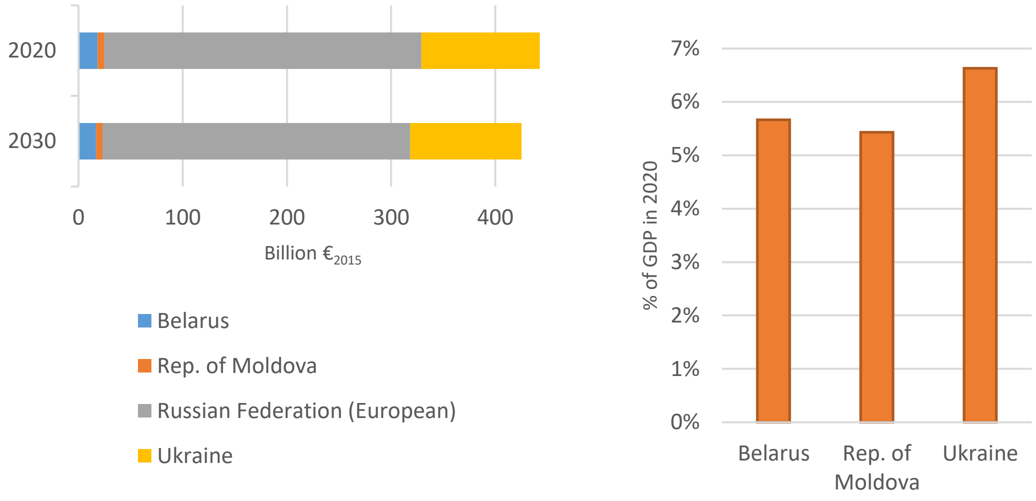
[10] https://www.ecb.europa.eu/stats/policy_and_exchange_rates/html/index.en.html.

[11] Cooperative Programme for Monitoring an Evaluation of the Long-Range Transmission of Air Pollutants in Europe.

[12] Hereinafter, EMEP domain as represented in GAINS Europe (v.3).

Figure 2

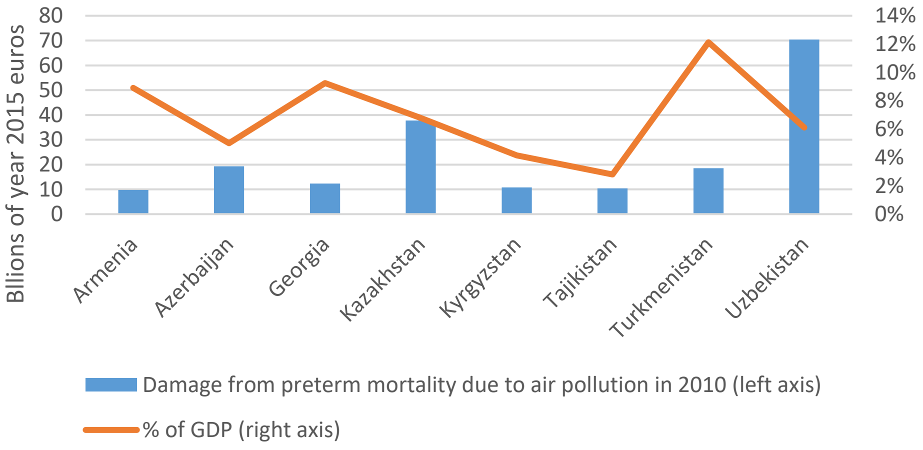
Health damage costs from air pollution in Eastern Europe, the Caucasus and Central Asia within the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe domain (calculations based on the current legislation scenario in Amann et al., 2020[5]).



25. For the Caucasus and Central Asia outside the EMEP domain, damage from preterm mortality attributable to poor air quality varied from approximately €9.8 billion in Armenia to over €70 billion in Uzbekistan in 2010 (see figure 3 below). This estimate is based on the mortality rates due to ambient air pollution presented in the World Health Organization (WHO) and OECD, 2015,[13] and a VSL value of €3.06 million[14] (year 2005 euros) as in Amann et al., 2020.[5] Mortality-related damage attributable to air pollution corresponds to 3–12 per cent of the countries' GDP.

Figure 3

Health damage costs from ambient air pollution in the Caucasus and Central Asia in 2010 (based on mortality presented in World Health Organization and Organisation for Economic Co-operation and Development, 2015)[13].



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[13] World Health Organization (WHO) Regional Office for Europe, OECD, 2015. Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth.

[14] VSL values in year 2005 euros are further adjusted with CPI-based inflation rates and changes in GDP per capita between 2005 and 2015 in the European Union-28, and differences in GDP per capita in 2015 between the European Union-28 and the considered countries.

Reduced labour productivity and other morbidity effects

26. Costs of reduced labour productivity (lost working days) due to illness constitute about 0.6 per cent of total health damage costs (mortality is valued with VSL), while all morbidity effects correspond to 5 per cent of total damage. OECD, 2016[1,3] estimates that damage from morbidity is in all regions dominated by costs of restricted activity days.

Damage to crops

27. In addition to premature mortality and illness in the population, air pollution has negative effects on crops – mainly through plants' exposure to ground-level ozone. These effects are easily monetized through market prices. OECD, 2016[3] projects that, in the Russian Federation, by 2060, crop yields will be 5 per cent lower than in the "no-feedback"[15] projection, corresponding to a 0.8 per cent decrease in value added in the agricultural sector.

Costs by pollutants

28. Costs of air pollution per ton emissions of main pollutants are presented in table 1 below. The values are obtained from Schucht et al., 2021[16] and represent health damage in the emitter country caused by $PM_{2.5}$ and ozone precursors. These damage values can be directly applied in damage costs assessments supporting air quality-related decision-making.

Table 1

Damage costs from air pollutants in Eastern Europe and the Caucasus, year 2015 euros/ton, Value of Statistical Life (source – Schucht et al., 2021[16], table 50).

Country	*NO_x*	*$PM_{2.5}$*	*SO_2*	*NMVOCs*	*NH_3*
Armenia	10 000	311 800	73 800	7 000	48 800
Azerbaijan	15 000	39 100	28 100	400	8 900
Belarus	4 100	77 300	20 400	100	11 000
Georgia	11 200	448 600	68 800	3 500	16 400
Rep. of Moldova	7 000	105 200	17 900	100	19 800
Russian Federation (EMEP)	4 500	110 500	34 700	1 400	37 700

Note: Data for Ukraine are not presented in Schucht et al., 2021[16]; and the figures from the previous modelling of damage from industrial air pollution in Europe (Holland et al., 2014)[17] are not comparable to those presented in table 1 above due to methodological differences, thus values for Ukraine are not included.

Abbreviations: NH_3, ammonia; NMVOCs, non-methane volatile organic compounds; NO_x, nitrogen oxides; SO_2, sulfur dioxide.

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[15] "No-feedback" baseline projection describes hypothetical baseline developments in absence of feedback effects of air pollution on the economy.[3]

[16] Schucht, S. and others, 2021. European Environment Agency. Costs of air pollution from European Industrial facilities 2008-2017.

[17] Holland, M. et al., 2014. Costs of air pollution from European industrial facilities 2008 -2012 – an updated assessment. EEA Technical report No 20/2014.

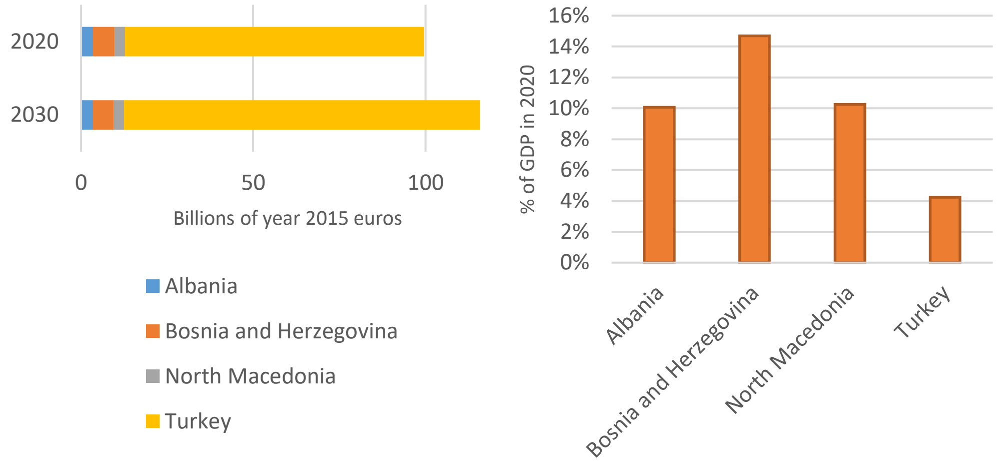
B. South-Eastern Europe

Total damage and per cent of gross domestic product

29. Health damage from ambient air pollution in South-Eastern Europe shows an ascending trend (see figure 4 below, left-hand panel): it is expected to increase from €100 billion in 2020 to €116 billion in 2030 (17 per cent increase) if no additional action is taken. Health damage attributable to air pollution constitutes 4–15 per cent of the countries' GDP in this region (see figure 4, right-hand panel).

Figure 4

Health damage costs from air pollution in South-Eastern Europe (calculations based on current legislation scenario in Amann et al., 2020)[5].



Reduced labour productivity and other morbidity effects

30. Costs of reduced labour productivity due to illness equal 0.7 per cent of total health damage costs (mortality is valued with VSL), and all morbidity effects constitute 10 per cent of total health damage.

Costs by pollutants

31. Pollutant-specific unit damage costs for South-Eastern Europe are summarized in table 2 below. These costs represent health damage in the region "European Environment Agency (EEA)38 + United Kingdom of Great Britain and Northern Ireland" caused by $PM_{2.5}$ and ozone precursors emitted in the listed countries. If health impacts of nitrogen dioxide (NO_2) precursors and impacts on crops and forests and material damage were to be added, damage costs would increase by 2 per cent for NMVOCs, and by 43 per cent for NOx on average in the region. As in EECCA, the greatest damage per ton pollutant results from $PM_{2.5}$ emissions, and the smallest from NMVOCs.

Table 2

Damage costs from air pollutants in South-Eastern Europe, year 2015 euros/ton, Value of Statistical Life (source – Schucht et al., 2021[16], table 21).

Country	*NO_x*	*$PM_{2.5}$*	*SO_2*	*NMVOCs*	*NH_3*
Albania	20 900	148 900	46 000	1 900	21 800
Bosnia and Herzegovina	27 200	104 600	40 600	2 700	50 600
Montenegro	14 700	36 700	26 500	1 700	30 700
North Macedonia	13 600	139 000	34 500	3 000	46 300
Serbia	20 900	168 900	44 200	2 800	74 400
Türkiye	10 100	90 800	23 600	1 700	23 400

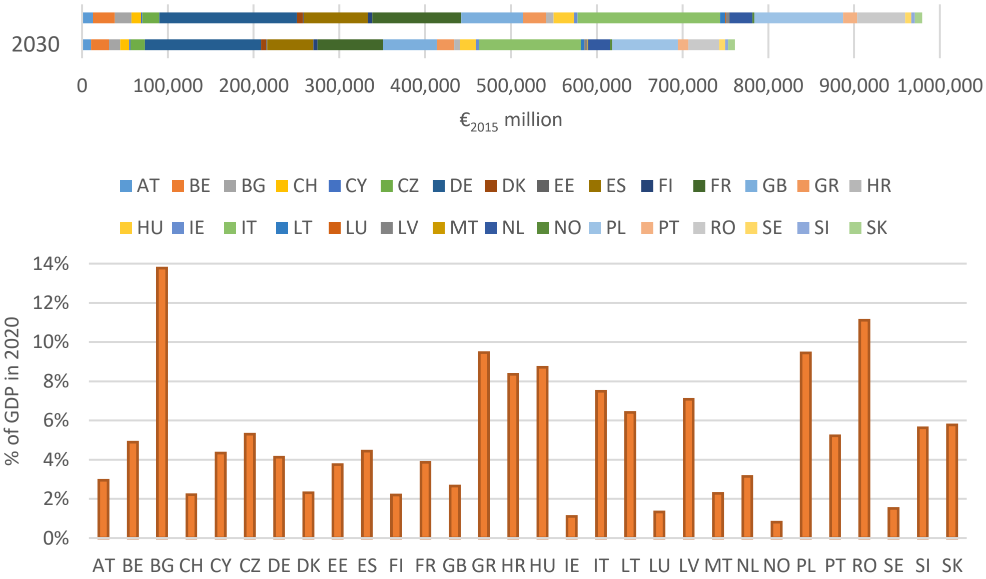
C. Western and Central Europe

Total damage and per cent of gross domestic product

32. For Western and Central Europe, total health-related damage from air pollution is estimated at approximately €980 billion in 2020 (see figure 5 below, upper panel). By 2030, this figure is expected to decrease to approximately €760 billion (a reduction by 22 per cent). In relation to GDP, country-specific damage varies from 1 per cent to around 14 per cent (the average value is 5 per cent) (see figure 5, lower panel).

Figure 5

Health damage costs from air pollution in Western and Central Europe (calculations based on the current legislation scenario in Amann et al., 2020[5]).



Abbreviations: AT, Austria; BE, Belgium; BG, Bulgaria; CH, Switzerland; CY, Cyprus; CZ, Czechia; DE, Germany; DK, Denmark; EE, Estonia; ES, Spain; FI, Finland; FR, France; GB, United Kingdom of Great Britain and Northern Ireland; GR, Greece; HR, Croatia; HU, Hungary; IE, Ireland; IT, Italy; LT, Lithuania; LU, Luxembourg; LV, Latvia; MT, Malta; NL, Netherlands; NO, Norway; PL, Poland; PT, Portugal; RO, Romania; SE, Sweden; SI, Slovenia; SK, Slovakia.

Reduced labour productivity and other morbidity effects

33. Costs of lost working days constitute about 1.1 per cent of total health damage costs; all morbidity effects account for 7 per cent of total damage (mortality is valued with VSL). For comparison, Holland et al., 2014[18] estimated the share of morbidity in total health damage from air pollution at about 9 per cent). According to a recent study exploring air pollution damage in Finland (Kukkonen et al., 2020),[19] productivity losses accounted for 0.3–3.4 per cent of health damage in 2015; the largest impact on labour productivity is observed for $PM_{2.5}$ emissions from non-road machinery in urban areas. Expected GDP reduction in 2060 due to labour productivity losses in Western and Central Europe is 0.1–0.3 per cent (OECD, 2016)[1].

34. Levels and sources of air pollution are different between rural areas and cities. Damage from air pollution in European cities exceeds €150 billion and largely depends on transport policies and corresponding emissions (see box 2 below).

Box 2

Zooming in on air pollution – city-level perspective (source - CE Delft, 2020[20]).

Recent analysis of health-related damage from air pollution in 432 large European cities in 30 countries estimates the total damage at over €166 billion (year 2015 euros) in 2018. Of this damage, 76 per cent is attributable to mortality (using VOLY) while 24 per cent is attributable to pain and suffering from illness. Annual damage per capita is €1,250 (year 2015 euros), which corresponds to 3.9 per cent of the cities’ income per capita. City size is identified as a key factor in the social costs of air pollution.

The study highlights the link between transport policies and the social costs of air pollution. It is estimated that a 1 per cent increase in the number of cars in a city results in 0.5 per cent increase in air pollution-related damage.

Damage to crops

35. Production of crops and wood in Europe is reduced by up to 15 per cent due to the harmful effects of ground-level ozone, depending on species sensitivity: annual losses for wheat production are estimated to be over €46 billion (Maas and Grennfelt, 2016).[21] Schucht et al., 2019,[22] show that in France, the monetized damage might be larger (figure 6). In France alone, current economic losses for production of crops and wood amount to approximately €2.4 billion. Damage is expected to decrease by 10 per cent within the next decade. Still, it will be equivalent to 8 per cent of costs of health damages from air pollution in France.

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[18] Holland, M., 2014, Cost-benefit Analysis if Final Policy Scenarios for the EU Clean Air Package, corresponding to IIASA TSAP Report #11.

[19] Kukkonen, J., et al., 2020. Modelling of the public health costs of fine particulate matter and results for Finland in 2015. Atmos. Chem. Phys., 20, 9371–9391, 2020, https://doi.org/10.5194/acp-20-9371-2020.

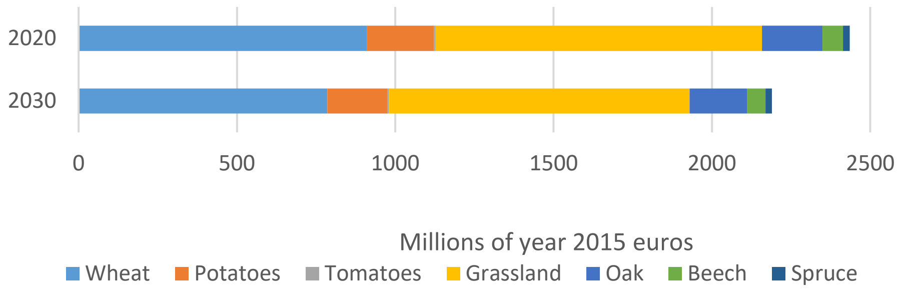
[20] de Bruyn, S., de Vries, J., CE Delft, 2020. Health costs of air pollution in European cities and the linkage with transport.

[21] Maas, R., P. Grennfelt, P., 2016. Towards Cleaner Air – Scientific Assessment Report 2016.

[22] Schucht, S., et al., 2019. Coût économique pour l’agriculture des impacts de la pollution de l’air par l’ozone – APollO : Analyse économique des impacts de la pollution atmosphérique de l’ozone sur la productivité agricole et sylvicole en France.

Figure 6

Economic losses from air pollution effects on crops and vegetables in France[22]**.**

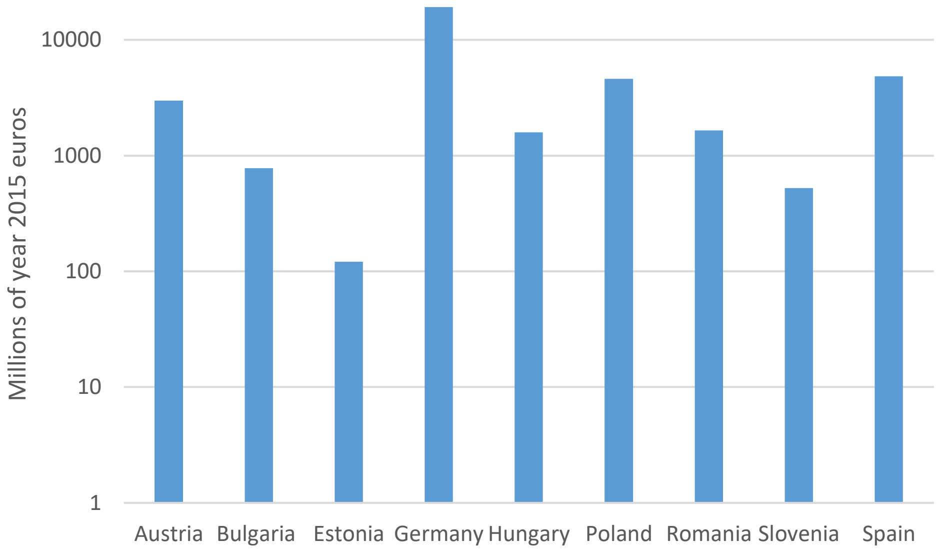


Costs by sectors and pollutants

36. In Europe, the main sector contributing to air pollution is transport (González Ortiz et al., 2020).[23] Total annual damage costs from road transport in the European Union-28 are estimated at up to €80 billion (CE Delft, 2018),[24] with large variations between countries illustrated in figure 7 below. About 75–83 per cent of damage from road transport is attributable to diesel sources.

Figure 7

Traffic-related air pollution damage costs in 2016 for nine European countries.[24] **Note the logarithmic scale of Y-axis.**



37. Available estimates of sector-specific costs of air pollution per ton emissions indicate large variations between sectors and pollutants (see figure 8 below).

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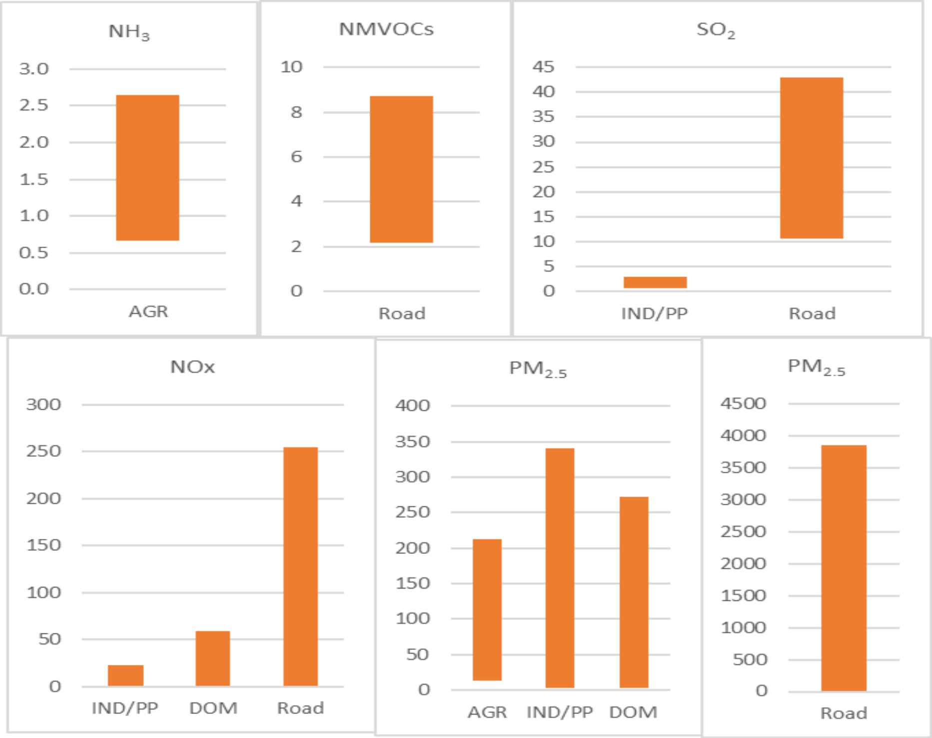
[23] González Ortiz, A., et al., 2020. Air quality in Europe – 2020 report, EEA Report No 09/2020.

[24] CE Delft, 2018. Health impacts and costs of diesel emissions in the EU.

Figure 8

Sector-specific damage cost ranges from air pollutants in Western and Central Europe, thousands year 2015 euros/ton[19,25,26,27,28].



Abbreviations: AGR, agriculture; Road, road transport; IND/PP, industries and energy; DOM, residential combustion.

38. Costs of air pollution per ton emissions (see table 3 below) also vary between countries depending on factors such as population structure and proximity to other countries. These costs represent health damage in EEA38+United Kingdom of Great Britain and Northern Ireland caused by $PM_{2.5}$ and ozone precursors emitted in the listed countries. If health impacts of NO_2 precursors, impacts on crops and forests and material damage were to be added in the estimates, damage costs would increase by 1 per cent for SO_2, 3 per cent for NMVOCs, and 134 per cent for NO_x (on average in the considered region). Unit costs of $PM_{2.5}$ are high (up to €540,000/ton), while unit costs of NMVOCs have the lowest values (€400–€14,000/ton), indicating the same relative input into total damage from different pollutants as in other countries in Europe.

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[25] Swedish Road Administration, 2018. Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.1.

[26] Birchby, D., et al., 2019. Air Quality damage cost update 2019, Report for Defra, AQ0650.

[27] Söderkvist, T. et al., 2019. Underlag för reviderade ASEK-värden för luftföroreningar, Slutrapport från projektet REVSEK.

[28] The Bruyn, S., et al., 2018. Environmental Prices Handbook EU28 version – Methods and numbers of valuation of environmental impacts.

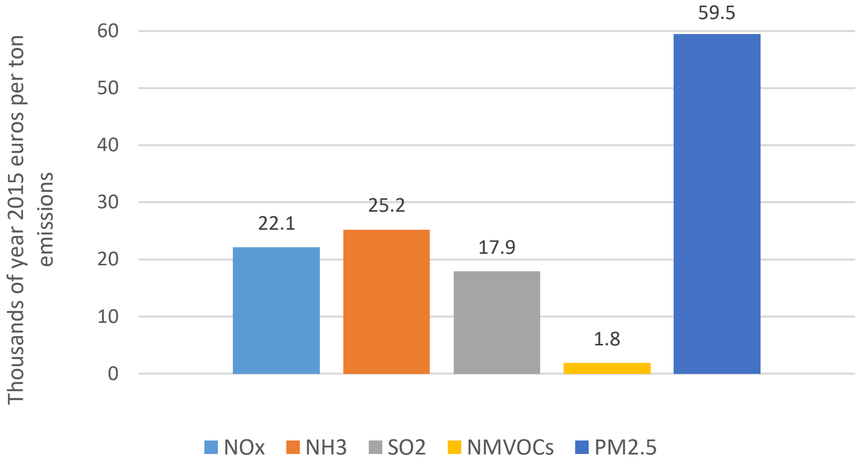
Table 3
Damage costs from air pollutants in Western and Central Europe, year 2015 euros/ton, Value of Statistical Life (source – Schucht et al., 2021[16], table 21).

Country	*NO_x*	*$PM_{2.5}$*	*SO_2*	*NMVOCs*	*NH_3*
Austria	48 800	206 400	102 300	7 400	68 300
Belgium	39 700	465 200	144 100	7 100	147 900
Bulgaria	22 600	281 300	41 900	2 500	52 700
Croatia	38 000	174 700	71 500	4 700	54 300
Cyprus	6 200	44 000	16 200	800	13 300
Czechia	30 700	256 600	64 100	7 300	119 600
Denmark	14 300	112 800	49 000	1 300	23 100
Estonia	2 300	24 300	6 000	400	11 300
Finland	2 700	59 400	15 400	500	12 300
France	37 500	189 200	100 800	5 500	38 400
Germany	40 600	242 300	105 200	5 000	82 100
Greece	4 600	132 400	33 100	3 100	37 200
Hungary	36 200	237 600	69 900	4 300	67 300
Ireland	21 400	45 600	70 700	1 600	14 000
Italy	62 100	538 500	85 000	14 000	84 100
Latvia	4 100	89 600	25 900	600	15 300
Lithuania	6 200	56 500	23 000	600	18 500
Luxembourg	49 400	224 900	135 900	4 100	75 100
Malta	900	136 500	15 200	2 200	79 100
Netherlands	44 100	267 700	122 800	5 400	101 800
Norway	4 400	51 600	13 900	1 000	8 800
Poland	12 000	117 500	38 100	2 700	63 800
Portugal	10 900	212 600	32 000	1 900	23 000
Romania	29 100	197 500	55 700	3 300	44 100
Slovakia	29 200	212 100	54 400	5 100	94 500
Slovenia	57 900	339 000	84 500	9 000	72 900
Spain	15 500	183 200	65 300	3 200	20 600
Sweden	5 700	48 600	18 200	800	15 700
Switzerland	88 100	278 600	210 300	11 000	58 800
United Kingdom	28 000	243 700	106 400	4 200	93 100

39. CE Delft, 2018[28] provides aggregated damage unit costs for the European Union-28 (see figure 9 below) that also show that the highest damage per ton emission occurs from $PM_{2.5}$.

Figure 9

Damage costs from air pollutants in the European Union-28, high Value of Life Year (source – CE Delft, 2018)[28].



D. North America

Total damage and per cent of gross domestic product

40. Estimates of historical total annual health damage from air pollution in the United States of America and Canada vary from €27 billion to over €500 billion (1–6 per cent of GDP), depending on year, effects considered, and chosen valuation metrics (see table 4 below).

Table 4
Estimates for damage from air pollution in North America, in billions of year 2015 euros

Country	*Year*	*Damage*	*Per cent of GDP*	*Included effects; chosen metric for valuation (if available)*	*Source*
United States	2010	150	1	Mortality, morbidity; VOLY	Im et al., 2018[29]
United States	2011	510	3	Mortality; VSL	Goodkind et al., 2019[30]
United States	2014	340	2	Mortality; VSL	Tschofen et al., 2019[31]
Canada	2016	82	6	Mortality, morbidity	Health Canada, 2021[32]
Canada	2015	27	2	Mortality and morbidity; VSL	Smith and McDougal, 2017[33]

Reduced labour productivity and other morbidity effects

41. Costs of morbidity in Canada are estimated at 5 per cent of the total health damage costs.[32] In all, 16 per cent of the morbidity costs (0.7 per cent of the total health damage costs) correspond to restricted activity days due to illness.

42. In Canada and the United States of America, air pollution is calculated to result in a GDP decrease of approximately 0.1 per cent in 2060 compared to a non-polluted situation due to reduced labour productivity (OECD, 2016).[1,3] Costs of morbidity per capita in North America in 2060 are projected to be around €100–€150 per year (see figure 10 below).

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[29] Im, U. et al., 2018. Assessment and economic valuation of air pollution impacts on human health over Europe and the United States as calculated by a multi-model ensemble in the framework of AQMEII3. Atmos Chem Phys. 2018 April 27; 18(8): 5967–5989. doi:10.5194/acp-18-5967-2018.

[30] Goodkind, A.L., et al., 2019,. Fine-scale damage estimates of particulate matter air pollution reveal opportunities for location-specific mitigation of emissions. PNAS, April 2019, vol.116, no.18, p.8775-8780, www.pnas.org/cgi/doi/10.1073/pnas.1816102116.

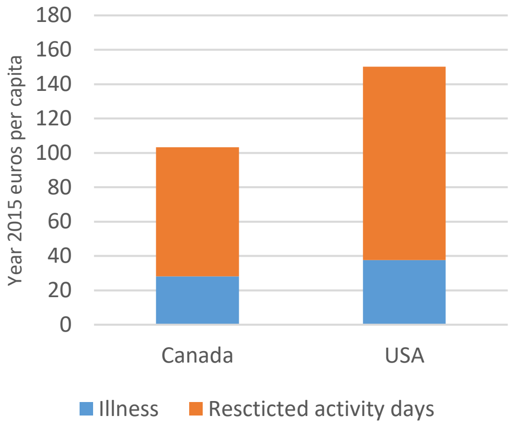
[31] Tschofen, P., et al., 2019,. Fine Particulate matter damages and value added in the US economy. PNAS, October 2019, vol.116, no.40, p.19857-19862, www.pnas.org/cgi/doi/10.1073/pnas.1905030116.

[32] Health Canada, 2021. Health impacts of air pollution in Canada – Estimates of premature deaths and nonfatal outcomes.

[33] Smith, R., McDougal, K., International Institute for Sustainable Development (IISD), 2017. Costs of air pollution in Canada – Measuring the impacts on families, businesses and governments. This study, although not based on the most recent and most Canadian-specific numbers on health effects or air pollution, provides the estimates on monetarized health damage for Canada, not included in many of the recent studies focused on mortality and morbidity effects of $PM_{2.5}$ and other pollutants.

Figure 10

Costs of morbidity in the United States of America and Canada in 2060, based on OECD, 2016[1].



Damage to crops

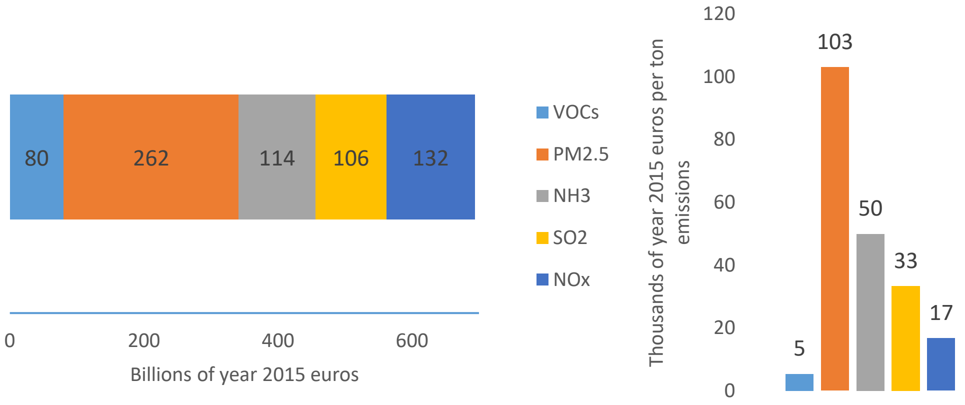
43. Air pollution’s effects on crops are significant in North America. OECD projections[3] indicate that, in the United States of America by 2060, agricultural production will fall by 4.9 per cent due to air pollution. The corresponding GDP decrease is projected at approximately 0.1 per cent.

Costs by sectors and pollutants

44. In the total costs of damage due to exposure to $PM_{2.5}$ in the United States of America (see figure 11 below, left-hand panel), primary emissions of $PM_{2.5}$ contribute about twice as much as contributions from secondary particles from NMVOC, NH_3, SO_x or NO_x emissions. Damage costs per unit emitted pollutant are highest for $PM_{2.5}$ (see figure 11, right-hand panel). Similar information for Canada is not published.

Figure 11

Contribution of pollutants to total damage from secondary $PM_{2.5}$ in the United States of America in 2011 (left, Goodkind et al., 2019)[30] and damage costs per unit emissions in the United States of America (right, Tschofen et al., 2019)[31].

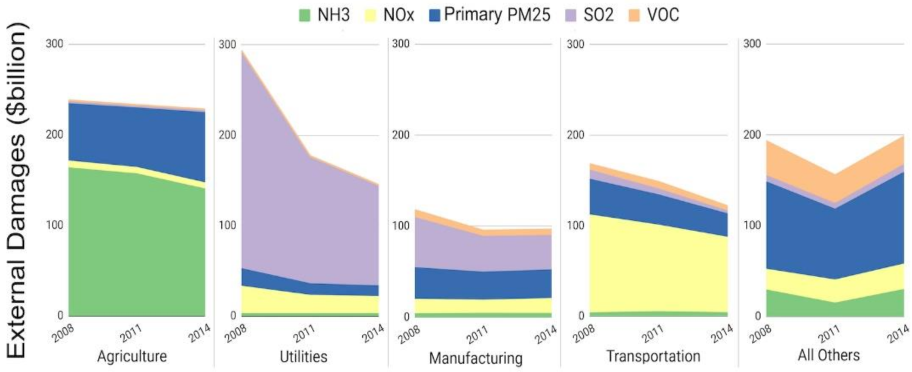


45. About 75 per cent of total damage from air pollution in the United States of America is estimated to be caused by activities in four sectors responsible for less than 20 per cent of GDP – agriculture, energy (utilities), manufacturing industries and transport (Tschofen et al., 2019).[31] These sectors have different pollution profiles: NH_3 causes a major part of the damage for agriculture; SO_x for energy and industries; and NO_x for transport (see figure 12 below).

46. For Canada, the recent studies[34] estimate that the anthropogenic activities contributing most to population-weighted $PM_{2.5}$ concentrations are transport and residential combustion. The total monetary value of the health burden due to road traffic in Canada is estimated at €6.7 billion. Contributions of passenger cars and heavy-duty vehicles (trucks and buses) are 37 per cent and 63 per cent, respectively.[35]

Figure 12

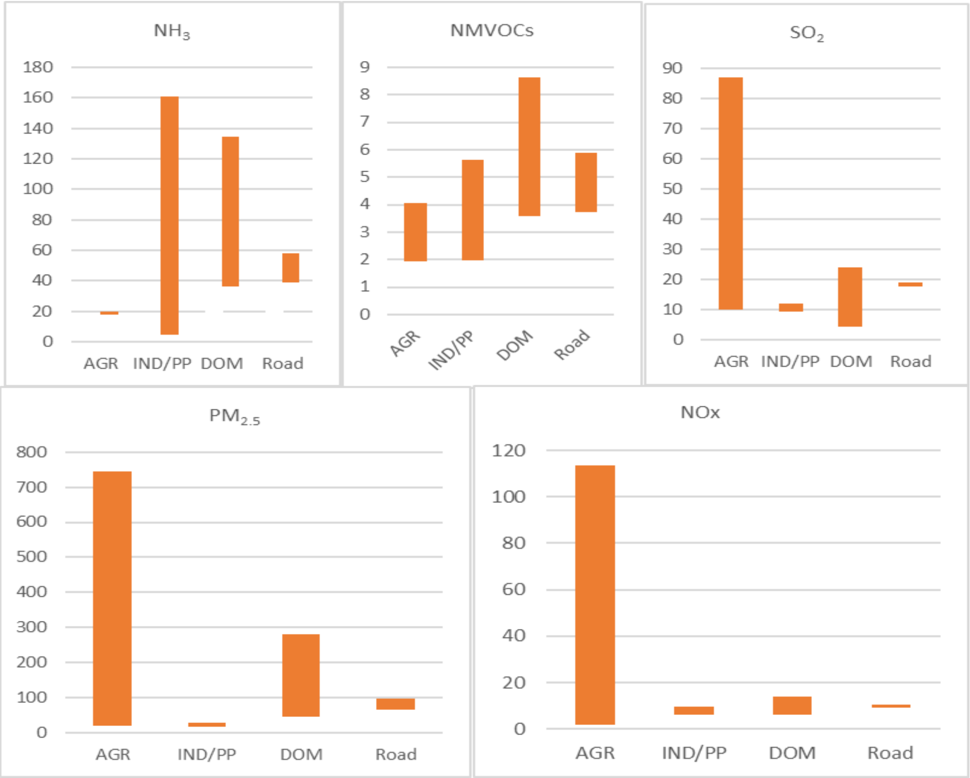
Health damage costs from air pollution in the United States of America, copied from Tschofen et al., 2019[31].



47. Intervals for sector-specific costs of these pollutants are summarized in figure 13. As in Europe, the highest unit damage is observed for $PM_{2.5}$, and the lowest for NMVOCs.

Figure 13

Sector-specific damage costs from air pollutants in the United States of America, thousand year 2015 €/ton (Goodkind et al., 2019[30], Schrader et al., 2018[36]).



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[34] Meng et al.., 2019, Environ Sci Technol. 2019 Sep 3;53(17):10269-10278.

[35] Health Canada, 2022. Health impacts of traffic-related air pollution in Canada.

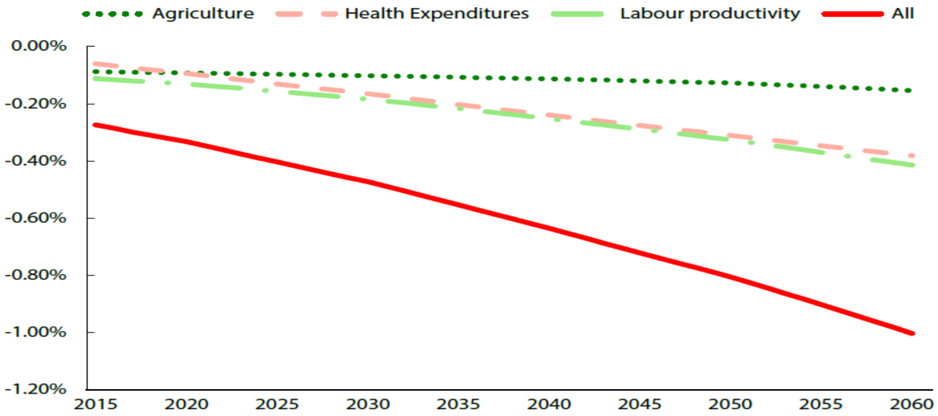
[36] Shrader, J., et al., 2018. Valuing pollution reductions – How to monetize greenhouse gas and local air pollutant reductions from distributed energy resources.

E. On a global scale

Total damage and per cent of gross domestic product, reduced labour productivity and other morbidity effects

48. A recent OECD study estimates that annual costs of premature mortality worldwide will increase from €2.4 trillion in 2015 to around €15 trillion–€20 trillion in 2060. Total damage from pain and suffering from illness is estimated to rise from €0.2 trillion in 2015 to €1.8 trillion, the annual number of lost working days to 3.7 billion, and health-care costs to €143 billion. Reduced labour productivity from air pollution is expected to cause global GDP loss of 0.4 per cent. The share of labour productivity effects on total market effects of air pollution is estimated at approximately 40 per cent (see figure 14 below). Non-market effects (costs of premature death and morbidity) exceed market effects by at least a factor of 8 (OECD, 2016).[1] The share of labour productivity losses of the total losses is estimated at 5–6 per cent.

Figure 14
Global market costs from air pollution, copied from OECD, 2016[1].



Damage to crops

49. Losses of crop yields due to air pollution vary significantly between countries. Macroeconomic models indicate they range from a <1 per cent to a 22 per cent decrease, compared to “no-feedback projection”.[15] However, since agriculture’s share in global GDP is relatively small, the global impact of air pollution on agricultural output is not significant, corresponding to approximately 0.1 per cent of GDP reduction in 2060 (OECD, 2016).[1]

Sector contributions

50. The sectors responsible for the largest contribution to global health damage costs from air pollution are road transport, household fuel combustion, agriculture and industrial coal burning (WHO and OECD, 2015).[13] About 50 per cent of total health damage in OECD countries is due to pollution from road transport. In 2010, the damage cost from this sector was estimated at €690 billion (OECD, 2014).[37] The global cost of air pollution from all fossil fuel combustion is estimated at €7 billion per day, or 3.3 per cent of the world’s GDP. In Bulgaria, Belarus, Hungary, Romania, Serbia and Ukraine, damage costs of fossil fuel combustion are estimated to exceed 5 per cent of GDP (Greenpeace, 2020).[38]

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[37] OECD, 2014. The Cost of Air Pollution – Health Impacts of Road Transport.

[38] Greenpeace, 2020. Toxic air: The price of fossil fuels.

VI. How much benefit will expected action bring in the future?

A. How large are the economic benefits that have been gained so far?

51. Retrospective assessments of economic benefits achieved from reduced air pollution are scarce. But available studies indicate, for example, that NH_3 emission compliance with the European Union National Emission reduction Commitments Directive[39] is estimated to have resulted in €14.6 billion in benefits from avoided premature deaths in the European Union-28 in 2016 (VSL) (Giannakis et al., 2019).[40] Estimates for the Netherlands show that, in 2015, the avoided health damage amounted to €35 billion per year (VOLY) compared to a "no action 1980–2015"-scenario; 53 per cent is attributable to emission reductions within the Netherlands (Velders et al., 2020).[41]

52. In North America, the Clean Air Act of the United States of America was estimated to result in annual benefits of €2 trillion from avoided premature deaths (VSL), morbidity, damage to crops and materials and recreational values. Of this figure, €10 billion is benefits in the agricultural sector, and €20 billion from reduced medical expenditures. The country's GDP growth due to the health effects of Clean Air Act implementation is estimated at 0.02 per cent (United States Environmental Protection Agency (US EPA), 2011).[42] In Canada, a substantial population-weighted average reduction in $PM_{2.5}$ of nearly 25 per cent (2.0 µg/m^3) was reported between 2000 and 2011, resulting in improvements in life expectancy of 0.1 years and reductions in mortality and morbidity of up to 3.6 per cent.[43]

B. European countries – forthcoming benefits from measures in place

53. Within Europe,[44] trends for health damage from air pollution depend on the considered region. In Western and Central Europe and in the EECCA countries the damage is expected to decrease in the next decade – the total annual benefits in 2030 are estimated at € 218 billion (approximately 0.9 per cent of current GDP, on average) and €17 billion (approximately 0.4 per cent of current GDP), respectively, compared to 2020 (see figure 15 below). In all, 2 per cent of the gained benefits are due to an increase in labour productivity, 6 per cent to other morbidity effects, and 92 per cent to avoided premature mortality. In South-Eastern Europe, the total damage trend is ascending – in 2030, air pollution is expected to cost €16.5 billion more than in 2020. Total avoided annual health damage from air pollution within the EMEP domain in 2030 is estimated at €219 billion (14 per cent, in relation to 2020).

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[39] See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.344.01.0001.01.ENG&toc=OJ:L:2016:344:TOC.

[40] Giannakis, E., et al., 2019. Costs and benefits of agricultural ammonia emission abatement options for compliance with European air quality regulations, Environ Sci Eur (2019) 31:93, https://doi.org/10.1186/s12302-019-0275-0.

[41] Velders, G.J.M., et al., 2020. Effects of European emission reductions on air quality in the Netherlands and the associated health effects. Atmospheric Environment 221 (2020) 117109, https://doi.org/10.1016/j.atmosenv.2019.117109.

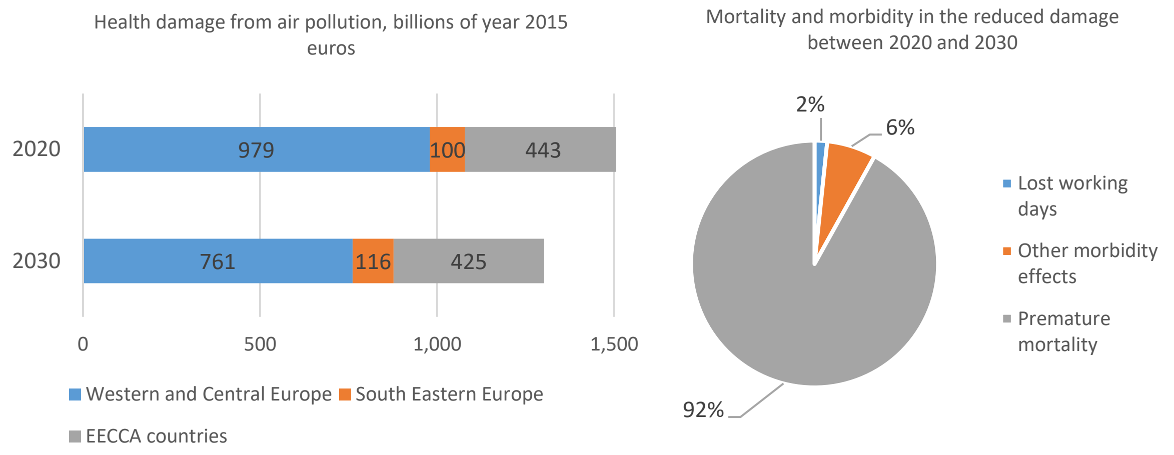
[42] US EPA, Office of Air and Radiation, 2011. The Benefits and Costs of the Clean Air Act from 1990 to 2020.

[43] David M. Stieb et al., Estimate public health impacts of changes in concentrations of fine particle air pollution in Canada, 2000 to 2011, *Can J Public Health*, 2015 June 18;106(6): e362-8.

[44] "Europe" in the context of the present document refers to the EMEP modelling domain represented in Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) Europe (v.3). The split into subregions in section VI is the same as in section V; the only difference being that, in section VI, damage in the Eastern Europe, Caucasus and Central Asia (EECCA) countries is only estimated for the countries within the EMEP domain: Belarus, Republic of Moldova, Russian Federation (European territory) and Ukraine.

Figure 15

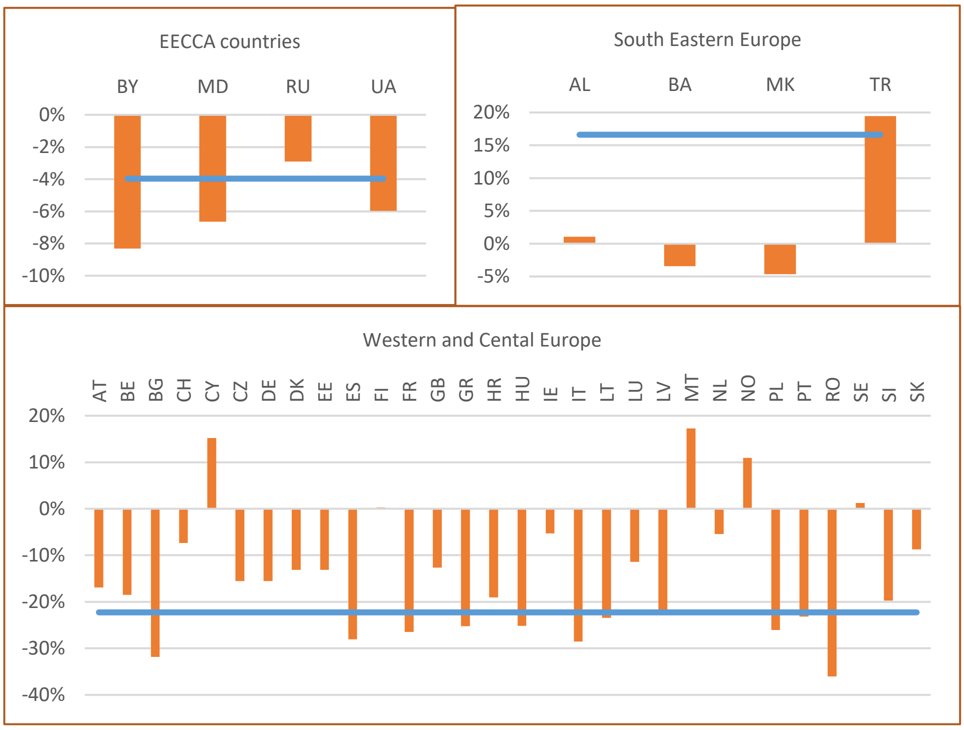
Estimated health benefits in European countries from agreed actions reducing air pollution (own calculations based on current legislation scenario in Amann et al., 2020[5]).



54. Some countries are expected to face a total increase in total premature mortality by 2030 despite the actions to be taken to reduce emissions: quick population growth and ageing are factors that, in some cases, outweigh positive effects of emission reductions and improved air quality on the total health damage – this is especially pronounced for South-Eastern Europe, where changing population structure in Türkiye seems to result in higher total health damage in 2030 than now (see figure 16 below).

Figure 16

Variations in the baseline damage reduction in 2030, in per cent to the 2020 level (own calculations based on current legislation scenario in Amann et al., 2020[5]). Blue line corresponds to regional average.



Abbreviations: AL, Albania; BA, Bosnia and Herzegovina; BY, Belarus; MD, Republic of Moldova; MK, North Macedonia; RU, Russian Federation; TR, Türkiye; UA, Ukraine.

55. An analysis for the European Union-27[5] shows that with already agreed measures, by 2050, the damage from premature mortality due to exposure to $PM_{2.5}$ is expected to decrease by 39 per cent, compared to 2020. Within the same period, premature deaths attributable to ground-level ozone will decline by 19 per cent.

56. Existing policy measures in the transport sector are expected to bring significant benefits in Western and Central Europe in the next decade – about €54 billion per year in 2030, compared to 2016. In this avoided damage, about 91 per cent is attributable to health effects, and 9 per cent is benefits from improved ecosystem services and prevented deterioration of buildings and materials (CE Delft, 2018).[24]

C. Air pollution and climate actions – what are the co-benefits?

57. Costs of technical air pollution measures and damage from air pollution could be reduced if air pollution legislation were to be enhanced by climate and energy policies. For example, the Climate and Energy (C and E) framework adopted by the European Commission in 2014 is expected to result in reduced emissions of air pollutants of up to 10 per cent in 2030, compared to a previously used baseline scenario. When considering the C and E framework, the air pollution abatement costs become 4 per cent lower and the avoided damage costs 5 per cent higher than in the previous baseline. IIASA[45] estimated that 27 per cent of the European Commission health improvement target for 2030 would be achieved through realization of the C and E framework scenario.

VII. Can damage costs be further avoided in the future?

58. Legislation in place will reduce health damage in the near future, but more benefits can be gained by raising the ambition level.

59. OECD, 2020,[46] estimates that a 1 $\mu g/m^3$ decrease in annual $PM_{2.5}$ concentration in the European Union would increase Europe's GDP by 0.8 per cent. A 10 per cent reduction in $PM_{2.5}$ average concentration across Europe would increase European GDP by €93 billion–€185 billion, or €185–€370 per capita. About 95 per cent of the total effect of $PM_{2.5}$ concentration on economic output is due to reduced labour productivity per worker.

A. European Union-27 beyond the baseline

60. Recent analysis in the second Clean Air Outlook[5] shows that, within the European Union-27, implementation of measures in accordance with NAPCPs could result in additional health benefits of about €8 billion–€43 billion annually. Additionally, European Union countries could gain about €305 million–€900 million annually from reduced damage to materials, crops, forests and natural ecosystems. If all technically feasible measures were to be applied irrespective of costs (MTFR scenario), annual health benefits could reach €153 billion–€205 billion in 2050, accompanied by €2.2 billion–€5 billion in non-health benefits. The numbers above reflect the range of four valuation options (core VOLY, core VSL, supplementary VOLY, supplementary VSL). Figure 17 illustrates benefits from NAPCPs and the MTFR scenario (core VSL).

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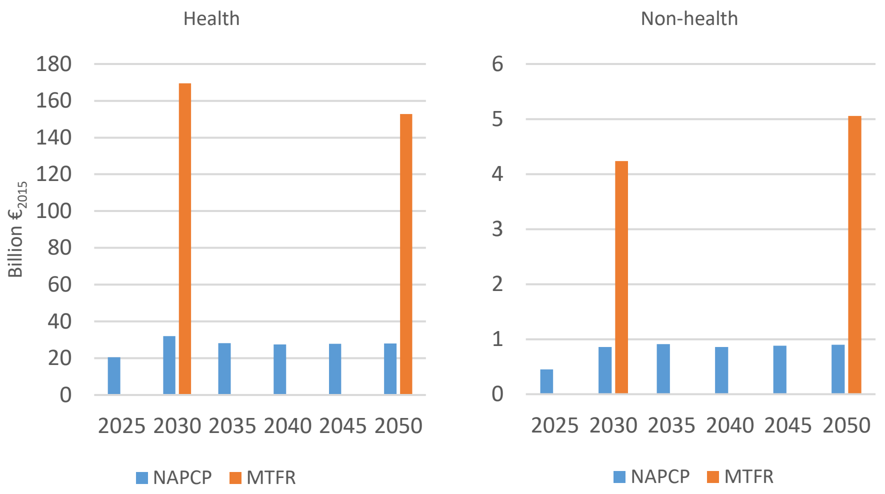
[45] Amann, M., Heyes, C., Kiesewetter, G., Schöpp, W., Wagner, F., IIASA, 2014. Air Quality – Complementary Impact Assessment on interactions between EU air quality policy and climate and energy policy.

[46] Dechezleprêtre, A, Rivers, N., Stadler, B., OECD, 2020. The economic cost of air pollution: Evidence from Europe, Economic Department working papers No.1584.

Figure 17

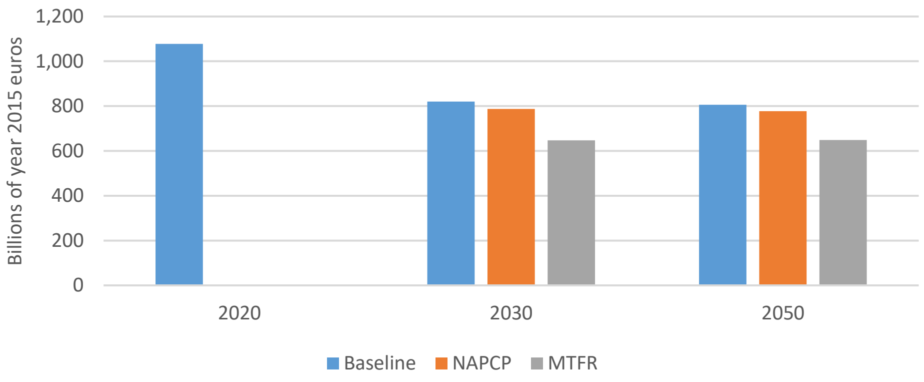
Total avoided health and environmental damage in the European Union-27 compared to the baseline scenario (source – Amann et al., 2020)[5] (core VSL).



61. While baseline development will lead to a 24 per cent damage reduction in 2030, compared to 2020, introducing NAPCP measures will mean a 27 per cent reduction, and applying all technically feasible measures a 40 per cent reduction (see figure 18 below).

Figure 18

Avoided damage in the European Union-27 due to additional measures beyond the baseline scenario (source - Amann et al., 2020)[5] (core VSL).



62. In the European Union transport sector, a faster uptake of zero emitting vehicles and a ban on pre-Euro 6 vehicles in all major cities would result in welfare benefits corresponding to €5.2 billion per year in 2030 due to improved health, reduced mortality (VOLY), better crop yields and biodiversity. More ambitious policies – e.g. bans on pre-Euro 6 vehicles, road pricing and reduced car use in cities – would bring €10.5 billion in benefits (CE Delft, 2018).[24]

B. Potential benefits in Eastern and South-Eastern Europe

63. In the Eastern and South-Eastern European countries, emission reduction potentials are now higher than in Western Europe. Measures in the energy sector could result in 60 per cent reductions of SO_2 in relation to baseline emissions (Maas and Grennfelt, 2016).[21] During the revision of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone in 2011, potential emission reductions in the EECCA and non-European Union Balkan countries (MTFR scenario) in 2020 were estimated at 75 per cent below the baseline for

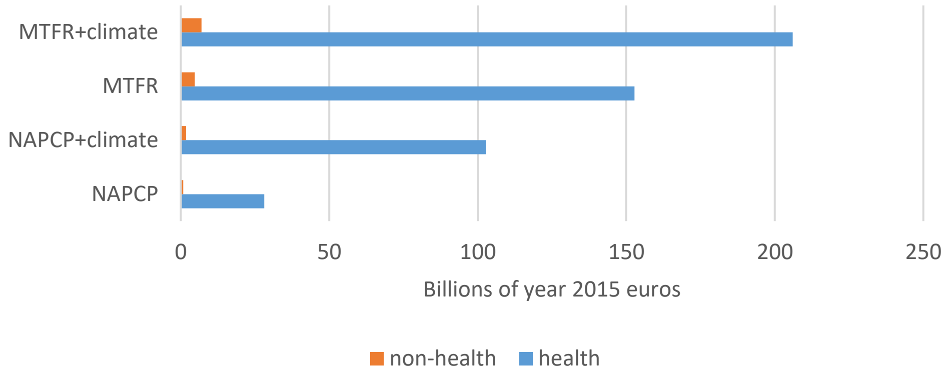
$PM_{2.5}$, and 39 per cent below the baseline – for NO_x, with a resulting 43 million years of life gained (Amann et al., 2011).[47]

C. More co-benefits from climate action

64. Even greater benefits can be achieved if air pollution reduction measures are effectively combined with policies and measures targeting greenhouse gas emissions, such as fuel transitions or behavioural changes reducing energy demand. The second Clean Air Outlook[5] indicates significant additional damage reductions (both health and other effects included) in the European Union-27 if air pollution reduction measures are applied in the 1.5 LIFE scenario of the European Union 2050 climate strategy vision – €76 billion for NAPCP measures, and an additional €55 billion for MTFR in 2050 (see figure 19 below).

Figure 19

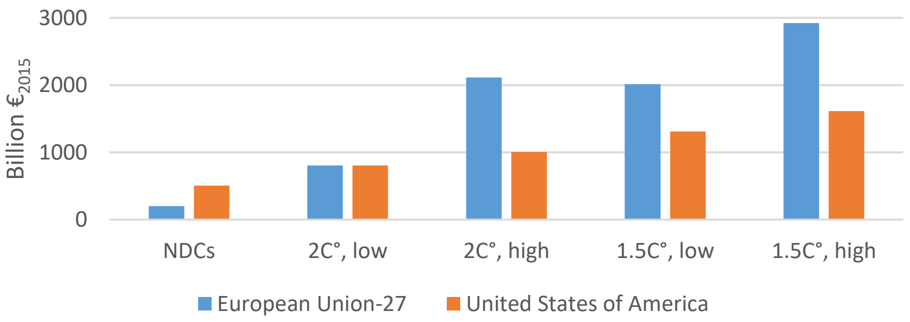
Damage, environmental and health benefits in the European Union-27 in 2050, based on Amann et al., 2020[5] (core VSL).



65. Health co-benefits from different ambition levels of climate policies provided in Markandya et al., 2018[48] show that, while current Nationally Determined Contributions (NDCs) would result in €200 billion lower damage in Europe (cumulative over the period 2020–2050), a 2°C target implies €800 billion–€2,100 billion health co-benefits, and with the target of 1.5°C, €2,000 billion–€2,900 billion in health damage can be avoided by climate policy. For the United States of America, health co-benefits are estimated at €500 billion with current NDCs, and up to €1,600 billion with higher ambition levels of climate policy (see figure 20 below).

Figure 20

Cumulative health co-benefits from climate policies 2020–2050, based on Markandya et al., 2018[47](VSL).



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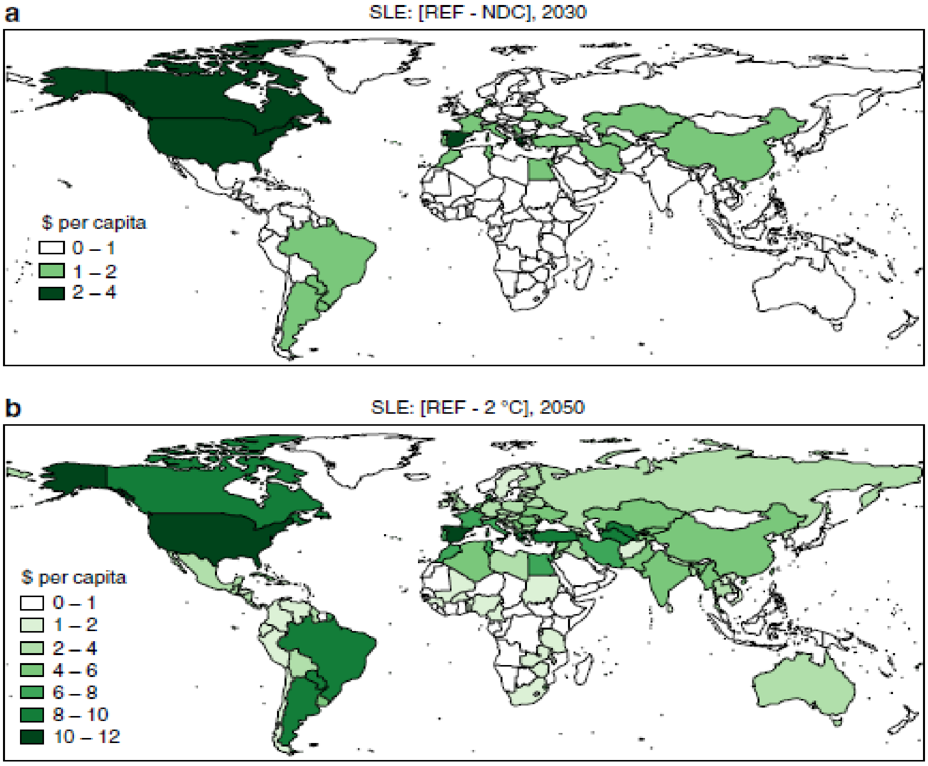
[47] Amann, M. et al., 2011. An updated set of scenarios of cost-effective emission reductions for the revision of the Gothenburg Protocol, CIAM report 4/2011.

[48] Markandya, A., et al., 2018. Health co-benefits from air pollution and mitigation costs of the Paris Agreement: a modelling study, Lancet Planet Health 2018; 2: e 126–33.

66. Effective climate policies also bring air pollution-induced co-benefits from crop yields. Ozone-related crop productivity improvements per capita resulting from NDCs and the 2°C target are highest in the Western part of the ECE region – in particular, the United States of America, Canada and certain European countries such as Spain (see figure 21 below).

Figure 21

Ozone-related crop yields co-benefits from climate policies, copied from Vandyck et al., 2018[49]. Upper panel – difference between reference scenario and Nationally Determined Contributions in 2030; lower panel – difference between reference scenario and 2°C reduction scenario in 2050.



VIII. Are the avoided costs of inaction larger than emission control costs?

67. Several previous cost-benefit analyses supporting policy decisions in the ECE region indicated that a significant part of potential emission reductions can be done at costs that are lower than benefits gained from improved air quality. For instance, welfare benefits from the Clean Air Act of the United States of America are estimated to be more than 30 times higher than implementation costs (US EPA, 2011).[41]

68. According to the cost-benefit analysis (CBA) of final policy scenarios for the European Union Clean Air Package (Holland et al., 2014),[18] annual net health benefits from the suggested national emission ceilings range from €42 billion to €164 billion in 2030, at costs of around €4 billion. This means that benefits are about 10–40 times higher than costs. Considering the C and E framework, which implies lower abatement costs and larger benefits (see figure 22 below), the benefit-to-cost ratio and the net benefits at the same ambition level are even higher. Furthermore, considering that the finally agreed emission reduction commitments were less ambitious than the ambition levels analysed in Holland et al. (2014), the benefit/cost ratio is higher than 10–40.

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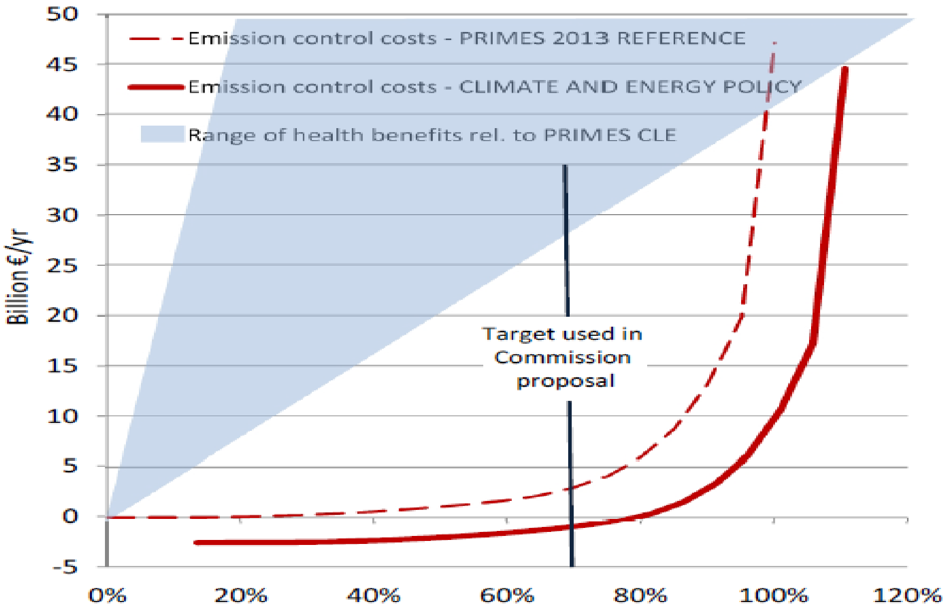
[49] Vandyck, T., et al., 2018Air quality co-benefits for human health and agriculture counterbalance costs to meet Paris Agreement pledges, NATURE COMMUNICATIONS | DOI: 10.1038/s41467-018-06885-9.

Figure 22

Costs and benefits of different ambition levels of air pollution policies (100 per cent corresponds to full implementation of all possible air pollution measures on top of the Price-Induced Market Equilibrium System 2013 reference economic scenario), in year 2005 euros. Copied from Amann et al., 2014[44].

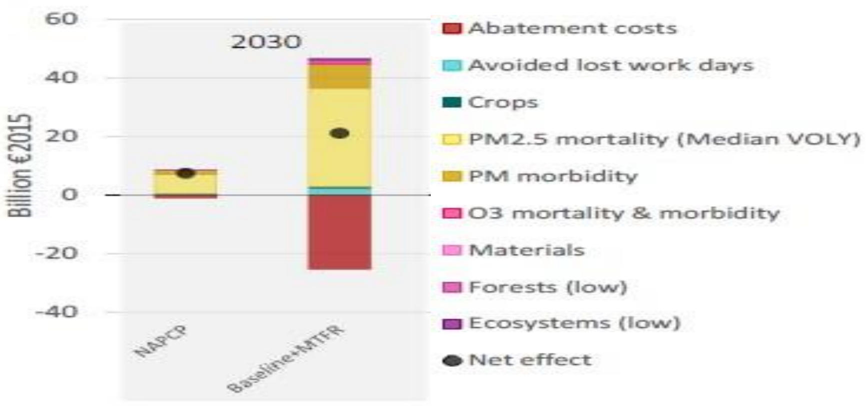


Abbreviations: PRIMES, Price-Induced Market Equilibrium System.

69. The latest assessment of costs and benefits from potential additional policy measures in the European Union-27 (Amann et al., 2020)[5] concludes that annual net health and environmental benefits (core VSL) from NAPCP measures in 2030 would amount to €31 billion, while the full implementation of technical measures would result in a net benefit of €146 billion. Benefits are estimated to be approximately 25 times higher than costs in the NAPCP scenario, and approximately 7 times higher in the MTFR scenario. Analysis of macroeconomic effects confirms these results (figure 23 below).

Figure 23

Cost-benefit assessment for the European Union-27 relative to the baseline. Copied from Amann et al., 2020[5].



70. The average costs of an optimal air pollution strategy are 0.01–0.02 per cent of GDP (Maas and Grennfelt, 2016)[21] – this could be compared to the approximately 5 per cent of GDP that air pollution welfare damages correspond to in Western and Central Europe.

71. Cost of action could be compared to cost of inaction also for specific pollutants, industries or facilities. Scarbrough et al., 2019[50] shows that measures assuring compliance with Best Available Techniques conclusions in the European steel industry would bring benefits that are 3.3–14 times higher than costs. Costs of action to abate ammonia are compared to the avoided damage in the recent Task Force on Integrated Assessment Modelling Assessment report on ammonia[51]. The comparison shows that benefits (€17.5/kg, CE Delft, 2018)[28] are 1.2–4.4 times higher than costs (€4–€15/kg, Wulf et al., 2017).[52]

72. Through analysis of costs and benefits at the facility level, decision-makers could make use of the estimated damage costs, available for all European ECE countries. Comparing avoided damage costs and comparing with costs of suggested technical solutions could provide justification of investment decisions resulting in emission reductions beyond legally required levels (see box 3 below).

Box 3

Cost of action vs Cost of Inaction at the level of facilities – Case study of Apatity coal plant.

Case study of the Apatity coal plant

The Apatity combustion plant in the north-west of the Russian Federation (1,530 MWth thermal output) has been in operation since 1959, using coal as its main fuel to produce heat and power. The Expert Group on Techno-economic Issues (EGTEI) estimated annual abatement costs of installing equipment to reduce emissions of SO_2, NO_x and total suspended particles (TSP) – with wet flue gas desulfurisator, selective catalytic reduction, and electrostatic precipitator, respectively (see table 5). Avoided damages to health due to these abatement techniques are valued by applying country-specific unit damage costs from Schucht et al., 2021,[16] the range is €158 million–€469 million. Total annual costs are estimated at €27.4 million. Irrespective of whether VSL or VOLY is chosen, total benefits from avoided damages exceed costs, with a benefit-cost ratio of 6-17 (see figure 24 below).

Table 5

Parameters used for calculating costs and benefits of installation of cleaning technologies at Apatity coal plant, based on EGTEI, 2011, Schucht et al., 2021,[16] and GAINS model scenarios as in Amann et al., 2020[5].

Pollutant	*Emissions in 2008/2010, kt*	*Removal efficiency of equipment, per cent*	*Removed emissions, kt*	*Abatement costs, millions of year 2015 euros*	*Avoided damage, millions of year 2015 euros*	
					Low VOLY	*High VSL*
TSP	6.23	99.9	6.18	5.3	-	-
$PM_{2.5}$	0.37	96	0.36		13	44
NO_x	2.4	75.4	1.8	10.5	2.7	7.9
SO_2	12.6	95.4	12.0	11.6	142	417
Total	**-**	**-**	**-**	**27.4**	**158**	**469**

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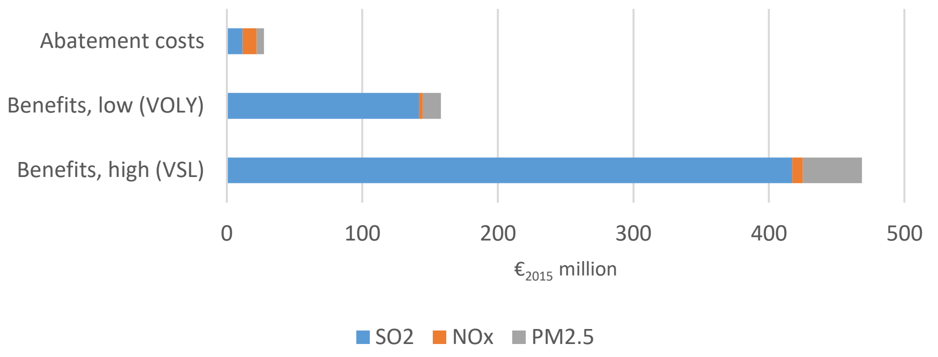
[50] Scarbrough, T., et al., 2019. Ex-post assessment of costs and benefits from implementing BAT under the Industrial Emissions Directive. Final Report for the European Commission – DG Environment, ED 10483, Issue Number 7.

[51] TFIAM 2021. Assessment report on ammonia. ECE/EB.AIR/WG.5/2021/7.

[52] Wulf, S., et al., 2017. Ammoniakemissionen in der Landwirtschaft Minderungsziele und –potenziale Aktuelle rechtliche Rahmenbedingungen für die Tierhaltung, Thünen, Hannover 30.05.2017.

Figure 24

Costs and benefits of installation of cleaning technologies at Apatity coal plant, based on EGTEI, 2011 and Schucht et al., 2021[16].



Notes: EGTEI, 2011. Apatity combustion plant – SO_2, NO_x and TSP emission reduction cost abatement, provisional report.

IX. Closing remarks

73. The answers to the guiding questions can be summarized as follows:

(a) *Can welfare effects of poor air quality be confidently estimated?* The results presented in this document are extracted from numerous studies carried out by several independent research groups. Although numerical values can vary due to differences in underlying assumptions, all studies show substantial welfare effects of poor air quality. Correspondingly, there is high confidence in the possibility to estimate at least the lower end of welfare effects from changes in air quality;

(b) *How high are the damage costs when action is not taken on air pollution?* Air pollution costs are currently substantial. For almost half of the countries in the ECE region, aggregated damage costs correspond to approximately 5 per cent of GDP;

(c) *Are these damage costs expected to go up or down in the future?* Future scenarios are foremost available for Western Europe. Through existing policies, monetary damage in the EMEP domain is expected to be 14 per cent lower in 2030 than today;

(d) *How can the costs of inaction be further reduced?* Further reduction of the damage costs is available through implementation of policies beyond those included in the current legislation;

(e) *Will human welfare improve if more is done?* Potential welfare improvements are closely linked to emission reduction policies. Of the European Union damage costs expected to remain in 2030, 21 per cent can be removed through additional policy actions.

74. Economic valuation of air pollution provides useful information on damage costs (socioeconomic welfare losses) of air pollution and thereby enables direct comparisons of economic activities with environmental and human health effects and valuation of reduced damages/increased benefits of further emission reductions, or, when solutions are available but not implemented, the damage costs of inaction.

75. The damage cost approach is a useful tool to assess unintentional welfare effects of new infrastructure investments or installations but requires further development. To support decisions on new projects or permits, several countries apply damage costs per unit of emission, to quickly scan potential additional damage to health and ecosystems from those activities and to decide whether additional air pollution measures are required and proportional. Often, these assessment tools only look at local or national damage, while (avoided) transboundary damage is omitted. Other important omitted damages are damages on biodiversity and some health effects. A comprehensive assessment would require including all external effects, including transboundary impacts. There are also considerable

information gaps between the Eastern and Western parts of the ECE region, especially regarding valuation studies carried out by East European research groups and scenarios for future air pollution levels in Eastern Europe.

76. Available cost-benefit analyses indicate that, in most cases, the costs of reducing emissions are far lower than the corresponding reduction of damage costs.

77. A summary of the methodology and data availability is presented in table 6 below, which also indicates comparable data sets. Major data gaps identified are:

(a) Lack of total damage estimates for recent years for ECE countries outside the EMEP domain[3] (except for Canada and the United States of America): Armenia, Azerbaijan, Israel, Kazakhstan, Kyrgyzstan, the Russian Federation (Asian part), Tajikistan, Turkmenistan and Uzbekistan, and smaller countries within the EMEP domain;

(b) Lack of analyses of future damage in the regions outside the EMEP domain[3]. The GAINS model v.4[53], under which more countries are included, enables future assessments of damage with broader geographical coverage.

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[53] https://gains.iiasa.ac.at/models/gains_models4.html.

Table 6
Estimates summary of the method and main data sources.

Aspect analysed	*Method, main sources*
Current total monetized damage and per cent of GDP	EMEP-domain: GAINS-ARP modelling for 2020, 2030 (figures 2 and 4–5) Caucasus and Central Asia – mortality rates for 2010 from literature[13] in combination with VSL (figure 3) North America and global – literature[1,29,30,31,32,33], values for the period 2010–2015 (table 4)
Country-specific damage costs per pollutant	EECCA: literature[16]; damage only in the emitter countries (tables 1–2) Western and Central Europe: literature[16]; damage in EEA38+ United Kingdom (table 3), European Union: average from literature[28] (figure 9) North America: average for United States only from literature[31] (figure 11), no country-specific estimates
Damage costs per sector	Europe: literature[19,25,26,27,28] (figure 8) North America[34,35]: literature (figure 13)
Labour productivity, damage to crops	Examples from literature[13] for Western Europe (figure 6)[22], Russian Federation, and North America (figure 10)
Benefits achieved in the past	Examples from literature for Europe[39,40] and North America[42]
Future benefits from measures in place	EMEP domain: GAINS-ARP modelling for 2020, 2030 (figures 15–16). No monetary assessments for other regions
Benefits beyond the baseline	Western and Central Europe: literature[5] (figures 17–18). No monetary assessments for other regions
Potential co-benefits from climate actions	Examples from literature for Europe[47] (figures 19–20) and North America[47] (figure 20), a global example[48] (figure 21)
Costs v. benefits	Examples from literature for Europe[42,5,21,28,49,51] (figures 22–23) and North America[41] Own CBA at plant level (box 3) based on assessments of emission reductions and damage costs from literature[16]

Abbreviations: ARP, Alpha RiskPoll.

78. It is important to continue efforts to improve the coverage of the values included in valuation studies. All the observed health effects of air pollution should be monetized, and values of ecosystem effects such as biodiversity effects should be better represented. It is also important to develop more assessments of current and future sector-specific marginal damage costs, especially for Eastern and South-Eastern Europe.