INTERIM METHODOLOGY

Air Pollution

Environmental Topic Methodology

Table of Contents

Executive Summary

- The Interim Air Pollution Topic Methodology can be used by preparers of impact accounts to measure and value the impact of air pollution on people and the natural environment. The Interim Air Pollution Methodology can also be applied by users of impact information to manage the sustainability-related risks, opportunities, and impacts of an entity and inform decision-making regarding an entity's contribution to sustainability.

- To use this methodology, preparers should:

    - develop a full accounting of air pollution across the entity's own operations as well as upstream and downstream in the value chain, considered separately;

    - categorize air pollution per pollutant and location;

    - utilize the impact pathway and value factors developed in this methodology to convert air pollution into impact accounts;

    - present any related impact information with supplemental notes and qualitative commentary necessary to meet the qualitative characteristics of impact information.[1]

- **Section 1** introduces the purpose of the document, outlines key concepts and definitions, and defines the scope for the Methodology. As an interim methodology, the Interim Air Pollution Methodology complements official impact accounting methodologies produced by IFVI in partnership with the Value Balancing Alliance, and will be revised as part of the official Due Process Protocol with oversight from the Valuation Technical Practitioner Committee.

- **Section 2** develops the impact pathway for the Methodology, consisting of inputs, activities, outputs, outcomes, and impacts. The main impacts of air pollution are reduced human health, reduced visibility, and impacts on agriculture.

- **Section 3** establishes the data required from the entity to implement the Methodology. This includes air pollution in metric tons per pollutant by location.

- **Section 4** outlines the approach of the Methodology for measuring and valuing the impacts, including models of meteorological data to ascertain the significance of air pollution by location as well as research-based links between air pollution and impacts.

[1] See General Methodology 1: Conceptual Framework for Impact Accounting.

- **Section 5** articulates potential opportunities for further development of the Methodology as it proceeds through the Due Process Protocol.

- The development of this methodology builds on frameworks and protocols published by leading organizations in the impact management ecosystem and sustainability-related disclosures required by governing jurisdictions and international standard setters, including:

    - Capitals Coalition;
    - Ecosystem Service Valuation Database (ESVD);
    - European Sustainability Reporting Standards (ESRS);
    - Global Reporting Initiative (GRI);
    - Intergovernmental Panel on Climate Change (IPCC);
    - National Institute for Public Health and Environment, Netherlands;
    - The Transparent Project;
    - Value Balancing Alliance;
    - World Resources Institute (WRI); and
    - World Wide Fund for Nature (WWF).

1 Introduction

1.1 Document purpose

1. The purpose of this document is to outline the Interim Topic Methodology for Air Pollution (henceforth, the Interim Air Pollution Methodology or the Methodology).

2. Interim methodologies have been released by the International Foundation for Valuing Impacts as complements to the official *impact accounting methodology* being developed by the International Foundation for Valuing Impacts and the Value Balance Alliance. The content of the Interim Air Pollution Methodology builds on the General Methodology and is intended for use alongside other Interim, Topic, and Industry-specific Methodologies.

3. The impact accounting methodology measures and values the *impacts* of corporate entities (entities or an entity) in monetary terms for the purposes of preparing impact accounts and generating impact information. The Interim Air Pollution Methodology can be used to inform internal decision-making, investment decisions, and understand the significance of air pollution impacts of an entity.

4. Interim methodologies have undergone a detailed research and development process, but have not gone through the Due Process Protocol or been approved by the Valuation Technical and Practitioner Committee (VTPC). Interim methodologies will be further developed and revised through the Due Process Protocol according to the established annual VTPC work plan.

5. The Interim Air Pollution Methodology can be applied via this document and the Global Value Factors Database. Supporting resources include the Interim Air Pollution Model and the Interim Air Pollution Model Technical Manual for users interested in understanding and expanding the interim methodology at a more technical level.

6. Preparers of impact accounts should adhere to the Interim Air Pollution Methodology to the fullest extent possible and should disclose any deviations from it when shared with users of impact information.

1.2 Topic description

7. Air pollution refers to the presence of harmful substances or pollutants in the air that can have negative effects on human health, the natural environment, and the built environment. These pollutants can be released into the air through various corporate activities, such as industrial processes, transportation, energy production and the burning of fossil fuels.

8. The release of damaging pollutants is a consequence of many corporate activities and can create adverse effects on human health, the natural environment, economic activity, and tourism and recreation. For example, air pollution is a major contributor to respiratory and cardiovascular diseases, leading to increased morbidity and mortality rates. It also affects ecosystems, causing damage to vegetation and the acidification of precipitation. Air pollution also impacts visibility, which affects shipping and aviation and tourism and recreation and residential amenity value.

1.3 Scope and assumptions

9. The Interim Air Pollution Methodology considers the impacts of six pollutants (PM10, PM2.5, SO2, NOx, NH3, and VOCs), with several classes of pollutants being addressed in other methodologies. For example, greenhouse gas (GHG) emissions are omitted from this methodology. In addition, air pollution which results from waste incineration is covered elsewhere; key incineration pollutants are addressed in the Interim Waste Methodology.

10. The pollutants selected for inclusion within this methodology are those for which impact pathways are well understood. Several studies underpin the selection and methodology, including large-scale assessments conducted in the European Union (EU) and the United States (US) which analyze impacts from PM, NO_x, SO_x and NH_3, with some also including VOCs[2]. These studies are also applied as proxies for other countries and regions.[3]

11. The scope and boundaries of the Interim Air Pollution Methodology includes full value chain air pollution. This includes upstream, direct operations, and downstream as defined in General Methodology 1. An entities' own operations should be the same scope used for financial statements to ensure comparability. Value chain air pollution may be based on models and not directly measured due to the challenges of measuring upstream and downstream air pollution.

12. The Interim Air Pollution Methodology recognizes full responsibility of an entity for its upstream and downstream air pollution. Air pollution is attributed to an entity through physical or economic relationships by portioning the inputs or outputs of air pollution and determining the portion that is linked to the entity. The inclusion of value chain air pollution means that double counting will occur if aggregating across entities in the same value chain. However, this will not lead to double counting within an individual entity's impact statement.

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[2] See the following studies: Defra, 2011a; ExternE, 2005; Muller and Mendelsohn, 2007; OECD, 2009; Pope et al., 1995.

[3] See the following studies: Sengupta and Mandal, 2013; Pervin et al., 2008; World Bank, 2007.

13. Literature focusing on the impacts of air pollution consistently underscores the paramount importance of health impacts; therefore, this methodology prioritizes the health impacts of air pollution[4.] The most significant health impact comes from PM, including direct emissions and secondary PM from NOx, SO2, and NH3. We focus on these using an air dispersion model, which also considers the direct health impacts of SO2.

14. Although covered in some of the studies mentioned above, impacts on forests and timber, built environment and recreation are considered immaterial relative to those included in the methodology. Therefore, they have not been included in the Interim Air Pollution Methodology.

15. Ammonia (NH3) has a short lifetime in the atmosphere and most (by weight) is quickly deposited. While this process can have localized impacts on areas close to the emissions source, the impacts are small compared to impacts on health. Given this low relative impact, this secondary deposition in soil and water is omitted from this methodology. However, impacts associated with NH3 in wastewater are considered separately in the Interim Water Pollution Methodology.

16. CO is a toxic gas that can be fatal if inhaled in large quantities and impacts society through inhalation and O3 formation. However, it is excluded from this methodology because: it is mainly dangerous indoors, which is outside the scope; catalytic converter regulations have reduced urban CO emissions significantly; and its complicated relationship with NOx and VOCs may result in the double counting of secondary impacts. Reflecting this, CO is also excluded from other studies.[5]

1.4 Key concepts and definitions

17. For the purposes of applying the Interim Air Pollution Methodology, the following terms are defined as:

    a) **Primary pollutants:** Substances directly emitted into the atmosphere from various sources which cause immediate negative impacts. The primary pollutants incorporated into the methodology are $PM_{2.5}$, PM_{10}, VOCs, NO_x, SO_x and NH_3. They are defined below.

    b) **Secondary pollutants:** Substances that are not directly emitted into the atmosphere but are formed through chemical reactions between primary pollutants and other atmospheric components. These reactions often occur

[4] See the following studies: Muller and Mendelsohn, 2007; Pope et al., 1995; ExternE, 2005.

[5] See the following studies: Muller and Mendelsohn, 2007; Defra, 2011a; and ExternE, 2005.

under specific environmental conditions, such as the presence of sunlight. Negative impacts are felt because of the presence of the outcome of the chemical reactions. The secondary pollutants. Incorporated included in this methodology are Ozone (O_3) and secondary particulate matter. These are defined below.

c) **Particulate matter (PM):** PM refers to a range of different types of solid particles that are suspended in ambient air. PM is produced from burning of biomass and fossil fuels and the creation of dust from agriculture or industry. PM is classified according to particle size: PM_{10} refers to coarse particulate matter (particles with a diameter of 10 micrometers or less); $PM_{2.5}$ refers to fine particulate matter (particles with a diameter of 2.5 micrometers or less). PM_{10} is expressed exclusive of $PM_{2.5}$ in this document (and associated analyses) to avoid double counting.

d) **Volatile Organic Compounds (VOCs):** VOCs comprise a wide range of organic compounds which have a high vapor pressure under normal atmospheric conditions, for example benzene, aliphatic hydrocarbons, ethyl acetate, glycol ethers, and acetone. They are released in large quantities as a result of human activities such as the use of solvents in industrial processes, as well as from some natural processes.

e) **Mono-nitrogen oxides (NO and NO_2, commonly referred to as NO_x):** These are naturally present in the atmosphere but are also released in large quantities through the combustion of fossil fuels and particularly transport fuels.

f) **Sulfur oxides (SO_X):** SO_X is released through the processing of sulfurous mineral ores and from many industrial processes which involve burning of sulfurous fossil fuels. The vast majority of SO_x in the atmosphere comes from human sources.

g) **Carbon monoxide (CO):** CO is released through combustion of fuels and is also a by-product of numerous industrial and agricultural processes.

h) **Sulfates (SO_4^-) and nitrates (NO_3^-):** These are formed from SO_2 and NO_x respectively and are both types of $PM_{2.5}$.

i) **Ammonia (NH_3):** Ammonia production is mainly a result of agriculture, particularly from the waste of cattle and other livestock. Some nitrogen-based fertilizers can also result in NH_3 emissions to air. NH_3 is largely deposited into soil or water soon after emission, but a small portion may react with ambient air to form ammonium ions (NH_4^+) which also contribute to $PM_{2.5}$.

j) **Ozone (O_3):** Ozone is formed via a non-linear reaction between VOCs and NO_x in the presence of sunlight.

2 Impact Pathway

2.1 Summary

18. The impact pathway is the analytical framework adopted to identify series of consecutive, causal relationships, ultimately starting at an input for an entity's activities and linking its actions with related changes in people's well-being. It serves as the foundation of the impact accounting methodology.

19. Detailed components of the impact pathway are outlined in subsequent sections, leading to the measurement and valuation of an entity's air pollution in *Section 4: Outcomes, Impacts, and Valuation.*

20. The impact pathway for air pollution is as follows:

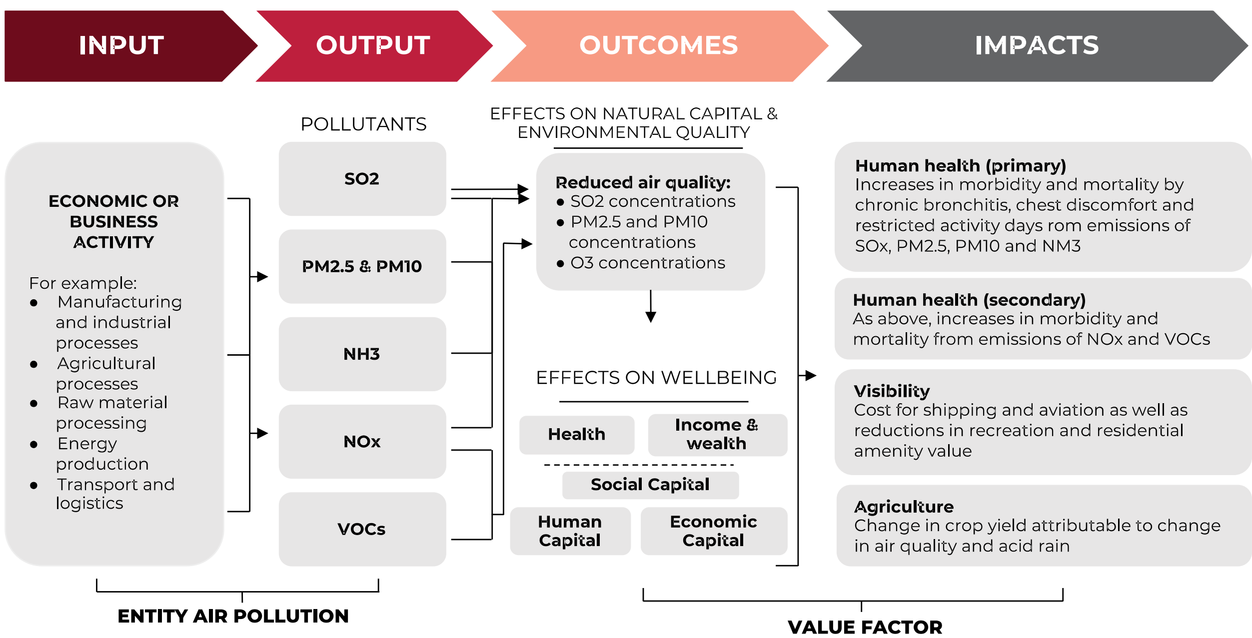

Figure 1: Air pollution impact pathway

2.2 Description and notes

21. The primary input for the air pollution impact pathway is the economic or business activity which lead to emissions of gaseous pollutants into the atmosphere. Emissions can arise from many different activities, such as the combustion of fuels, industrial processes, and activities where materials are broken down, such as tire wear from transport and construction activity. Additionally, agricultural practices, deforestation, and natural sources like wildfires and volcanic eruptions also contribute to air pollution.

If these are attributable to corporate activities, then they can be included in the impact pathway for a company's value chain.

22. Outputs from emitting activities give rise to gaseous pollutants which change the concentration of the pollutant in the atmosphere. Pollutants can be grouped in terms of primary pollutants such, PM, NOx, SOx, NH3, which react with other elements in the air to produce secondary pollutants such as VOCs. Emissions are typically calculated and reported in mass such as kg or metric tons.

23. Both primary and secondary pollutants lead to increases in their concentration in the atmosphere. These emissions reduce ambient air quality, with the impact pathway focusing on the following atmospheric pollutant concentrations:

    a) SO_2 concentration – resulting from emissions of SO_2.

    b) PM concentration – resulting from emissions of $PM_{2.5}$ and PM_{10} but also from secondary PM emissions from NO_x, SO_2 and NH_3.

    c) O_3 concentration – resulting from VOC and NO_x emissions.

24. Outcomes and impacts are principally related to health but also include impacts via agriculture and visibility:

    a) **Health impacts from primary pollutants** describe respiratory diseases. These impacts include increased incidence of chronic diseases such as asthma and bronchitis and, in some cases, premature mortality from cardiovascular diseases, pulmonary diseases and lung cancer.

    b) **Health impacts from secondary pollutants:** Impacts describe the coverage of the impacts on human health from the formation of Ozone (O_3). This valuation methodology traces the pathway from emissions of NO_x and VOCs (and NH3) to the formation of O_3. The methodology then estimates the health impacts of inhaled O_3 on the population and the resulting societal costs.

    c) **The impacts of visibility**: This valuation considers the visibility impacts of all six primary pollutants. This valuation methodology traces changes in these six pollutants and considers impacts including reduction in the quality of views (e.g., mountain vistas) as well as reduced visibility's impact on aviation, which can increase cost to the economy through disruption to travel.

    d) The impact pathway traces the impact of increased NO_x and VOCs emissions on **agricultural** productivity, and ultimately wellbeing via economic livelihoods and nutrition. This value factor is determined by the loss of crop output and is measured by the change in production value this causes.

25. Other impacts of air pollution are not covered in the methodology, due to their relatively low impact, with this methodology prioritizing the impacts with the largest societal cost. Other societal impacts from air pollution not covered include changes in growth of forestry and timber, loss of material due to increased corrosion from acid rain and the loss of ecosystem services.

3 Impact Driver Measurements

26. Impact drivers consider inputs and outputs and reflect the data needs expected of a preparer to provide an impact account for air pollution.

27. Data requirements for the Interim Air Pollution Methodology are aligned with and expand upon air pollution related sustainability reporting standards, which primarily captures the quantity of the same air pollutants discharged as those included in the methodology.

3.1 Data requirements

28. The Interim Air Pollution Methodology requires the mass of each air pollutant emitted, from a given source location (on the basis of countries or US states), in a given year, split by source type (urban, peri-urban, rural and transport). This methodology considers emissions of six key pollutants: PM10, PM2.5, SO2, NOx, NH3, and VOCs, although it should be noted that not all company activities will have significant pollutants in each category.

29. Information on the location type at the source of emissions is required for the selection of accurate value factors within the valuation formula. When selecting the relevant value factor for their emissions in the given country or US state, preparers of impact accounts will be required to select a factor from one of three source types:

30. Urban: An area with a high population density, extensive infrastructure and a concentration of buildings and services.

31. Peri-urban: A transitional area between urban and rural areas, which often contains industrial parks, business parks, and suburban developments with mixed land uses.

32. Rural: An area with low population density, open spaces and agriculture or natural landscapes.

Data input		Country 1	Country 2	Country 3
Air Pollution in Own Operations				
Metric tons of PM_{10}	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of $PM_{2.5}$	Urban			
	Peri-urban			

	Rural			
	Transport			
Metric tons of SO_2	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of NO_x	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of NH_3	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of VOCs	Urban			
	Peri-urban			
	Rural			
	Transport			
Air Pollution in Upstream Value Chain				
Metric tons of PM_{10}	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of $PM_{2.5}$	Urban			
	Peri-urban			

	Rural			
	Transport			
Metric tons of SO_2	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of NO_x	Urban			
	Peri-Urban			
	Rural			
	Transport			
Metric tons of NH_3	Urban			
	Peri-Urban			
	Rural			
	Transport			
Metric tons of VOCs	Urban			
	Peri-Urban			
	Rural			
	Transport			
Air Pollution in Downstream Value Chain				
Metric tons of PM_{10}	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of $PM_{2.5}$	Urban			
	Peri-urban			

	Rural			
	Transport			
Metric tons of SO_2	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of NO_x	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of NH_3	Urban			
	Peri-urban			
	Rural			
	Transport			
Metric tons of VOCs	Urban			
	Peri-urban			
	Rural			
	Transport			

Table 1: Air pollution data requirements

33. The data requirements of the Methodology aligns with and expands upon disclosure requirements established by relevant standard setters including European Sustainability Reporting Standards E2: Pollution and the Global Reporting Initiative 305: Emissions 2016. Additional alignment may exist with other regional or topic specific reporting standards as well.

Metric	ESRS	GRI
Air Pollution – own operations	Fully aligned with E2-4, paragraph 26 and 28, page 108	Fully aligned with Disclosure 305-7 (a)

Air Pollution – value chain	Expands upon E2-4, paragraph 26 and 28, page 108	Expands upon Disclosure 305-7(a)
Location of air pollution	Expands upon E2-4, paragraph 26 and 28, page 108 Expands upon E2-4, paragraph AR 22, page 112	Expands upon Disclosure 305-7 (a)

Table 2: Alignment with reporting standards[6]

3.2 Data sources, gaps, and uncertainty

34. Preparers should strive to measure air pollution in a manner that is complete, neutral, and free from error. This includes faithfully representing pollutants emitted from all parts of the value chain.

35. In practice, obtaining full value chain air pollution data may be challenging for entities, particularly from upstream or downstream in the value chain. Barriers such as cost, accounting methods, or availability of data may limit preparers from measuring, in their entirety, air pollution impacts.

36. Measurement of air emissions is best done on site using direct in-line measurement. However, this is rarely practical across entire value chains and, instead, the drivers of air pollution can be measured to estimate emissions indirectly. For example, the quantity and type of fuel together with the type of combustion engine can be used to calculate emissions from fossil fuel-based energy generation or transport.

37. If direct data on emissions or impact drivers (e.g., fuel use) are not available, modelling techniques such as environmentally extended input-output (EEIO) analysis or industry / lifecycle assessment databases can be used. Such approaches give different levels of data specificity depending on the application. For example, LCA databases are typically rich in data on specific plastics, but government agencies or the IPCC database are likely to provide more up to date information for electricity emission factors. Similarly, EEIO data are only as specific as the sector and geographical resolution provided in the model.

[6]Categories of alignment include (1) fully aligned: data from reporting can be used as is for preparation of impact accounts; (2) expands upon: data from reporting conceptually aligns with the impact accounting methodology, but additional detail, context, or presentation is necessary for an accurate accounting of impact; or (3) independent: Data needed for the preparation of impact accounts are not covered by the reporting standards and would require separate data collection and analysis.

38. In the instance that direct in-line measurement of emissions is not possible, it will need to be estimated from secondary data. Preparers should prioritize approaches that:

    a) Directly measure air pollution over those that estimate air pollution based on calculations from activity data,

    b) Utilize primary data from specific activities within a company value chain over secondary data, and

    c) Consider sources of data that are of the highest quality possible.[7]

39. High-quality data sources should consider:

    a) Technological representativeness. Does the data match the technology used?

    b) Temporal representativeness. Does the data represent the actual time or age of the activity?

    c) Geographical representativeness. Does the data reflect geographic considerations of the activity?

    d) Completeness. Is the data statistically representative of the activity?

    e) Reliability. Are the data sets or sources dependable?[8]

40. When assessing secondary data, preparers should first consider using data on key drivers of air pollution to calculate an estimation of emissions. For example, the quantity and type of fuel together with the type of combustion engine can be used to calculate emissions from fossil fuel-based energy generation or transport. Supplier questionnaires can be directed to areas of high materiality or those with limited quality data from other sources. Most companies tend not to measure air pollution directly but will have information on air pollution drivers such as fuel use, electricity consumption, waste to incineration, etc. Emission factors are required to convert these data to metric tons of different air pollutants.

41. If direct data on emissions or impact drivers (e.g., fuel use) are not available, modelling techniques such as Environmentally Extended Input Output Models (EEIO) models or industry / lifecycle assessment (LCA) databases can be used to produce emission

[7] Language adapted to air pollution from the Greenhouse Gas Protocol. (2011). *Corporate value chain (scope 3) accounting and reporting standard*.

[8] Language adapted to air pollution from the Greenhouse Gas Protocol. (2011). *Corporate value chain (scope 3) accounting and reporting standard*.

estimations. Such approaches give different levels of data specificity depending on the application. For example, government agencies or the IPCC database are likely to provide more up to date information for electricity emission factors. Whereas EEIO data is only as specific as the sector and geographical resolution provided in the model.

42. Uncertainty will arise when quantifying air pollution. Preparers should report qualitative uncertainty and, when possible, quantitative uncertainty. These may include but are not limited to propagated measured uncertainty, pedigree matrices (tools used to assess the quality and reliability of data), sensitivity analyses, or probability distributions. Reporting uncertainty and other results may be done in accordance with the Value Notes guidance produced by the Value Commission of the Capitals Coalition.[9]

[9] https://capitalscoalition.org/project/the-value-commission/

4 Outcomes, Impacts and Valuation

43. The outcomes that result from air pollution include adverse health effects such as respiratory and cardiac illnesses, reduced visibility, and decreased agricultural productivity. In addition to the effects on natural capital and environmental quality, these outcomes lead to several impacts on well-being, including the categories of health, income and wealth, social capital, human capital, and economic capital.

44. The impact pathway in this statement has been developed using value factors that collapses the impact measurement and valuation stages into a summary value using detailed methodologies that model changes in pollutant concentrations and estimate societal costs. The value factors, available in the GVFD, can then be multiplied directly by entity-specific air pollution data using the equations in section 4.1. The measurement and valuation approaches are expanded upon in sections 4.2 and 4.3 and Appendix B.

4.1 How to calculate impacts

45. To determine the monetary cost of air pollution ($AP\ Value_{Total}$) preparers should use the following equation:

$$\textbf{AP Value}_{\textbf{Total}} = \sum(PH\ Impact_p + SH\ Impact_p + VIS\ Impact_p + AGR\ Impact_p) \quad \text{(Eq. 1)}$$

for all pollutants in all countries

$$PH\ Impact_p = Pollution_p * VF_{pl\ PH} \text{ for each country} \quad \text{(Eq. 2)}$$

$$SH\ Impact_p = Pollution_p * VF_{p\ SH} \text{ for each country} \quad \text{(Eq. 3)}$$

$$VIS\ Impact_p = Pollution_p * VF_{p\ VIS} \text{ for each country} \quad \text{(Eq. 4)}$$

$$AGR\ Impact_p = Pollution_p * VF_{p\ AGR} \text{ for each country} \quad \text{(Eq. 5)}$$

46. The variables in the equations are as follows:

$VF_{pl\ PH}$	The value factor for primary health for each air pollutant and the location type where the pollution occurred. These values are distinct for each country where pollution occurs. The value factor should be obtained for each country where pollution occurs from the Global Value Factors Database.
$VF_{p\ SH}$	The value factor for secondary health for each air pollutant. These values are distinct for each country where pollution occurs. The value factor should be obtained for each country where pollution occurs from the Global Value Factors Database.
$VF_{p\ VIS}$	The value factor for visibility for each air pollutant. These values are distinct for each country where pollution occurs. The value factor should be obtained for each country where pollution occurs from the Global Value Factors Database.

$VF_{p\ AGR}$	The value factor for agriculture for each air pollutant. These values are distinct for each country where pollution occurs. The value factor should be obtained for each country where pollution occurs from the Global Value Factors Database.
$Pollution_p$	The metric tons of air pollution released organized by the pollutant, location type, and country of release.
p	Type of pollutant (e.g. PM10 or SOx).
l	Location type (urban, peri-urban, rural, or transport). This consideration only applies to primary health effects.

47. The air pollution impact calculation is described below.

    a) Equations 2 - 5 calculate the monetary value of impacts for each of the four components of the air pollution impact pathway, including primary and secondary health, visibility, and agricultural impacts. These are organized based on the type of pollutant, location type (only for primary health) and country and are presented as part of the Global Value Factors Database. The value factor for each can be multiplied by the air pollution value for that pollutant and country. These equations should be calculated separately for each of the categories provided.

    b) After determining each impact, the total air pollution impact can be determined by summing the four impacts for each air pollutant, location type, and country.

48. Upstream value chain, downstream value chain, and own operations of air pollution should always be considered separately to increase transparency, comparability, and decision-usefulness. Additional levels of detail may be useful such as an assessment of waste production impact regionally, nationally, or within specific value chain categories.

4.2 Outcomes and impacts

49. The approaches used to link air pollution to outcomes and impacts are described below. Additional methodological details are in Appendix B.

50. Changes in pollutant concentrations in the atmosphere are modeled using a Lagrangian puff air dispersion model, ATMOS 4.0, which uses meteorological data to assess how emissions of pollutants disperse. Health outcomes from the changes in population exposure to air pollutants are modelled using linear dose response functions for pollutant exposure which assumes that emission concentrations are already above any damage threshold, such that any addition of pollution in the environment causes an

impact. This provides estimates of changes in mortality and morbidity from changes in air pollutant concentrations.

51. Other measures of outcomes and impacts are combined with assessments of societal cost as explained in the following section.

4.3 Monetary valuation

52. Monetary valuation uses value factors to estimate the relative importance, worth, or usefulness of changes in well-being indicators in monetary terms. The monetary valuation approach and value factors are developed individually for each impact. Each approach is described briefly below with additional methodological details in Appendix B.

    a) **Health impacts from primary pollutants:** The value factor estimates the societal cost of increases in respiratory or cardiac illness and premature death attributes to increased air pollution. To value the morbidity health outcomes Willingness to Pay (WTP) estimates from peer reviewed literature are used. For mortality, the OECD estimate of the value of a statistical life (VSL) is used, where the value is derived from the mean of 366 estimates from stated preference studies around the world. The VSL used is $4,889,008 in 2023 USD.

    b) **Health impacts from secondary pollutants impacts from ozone (O_3) formation:** The societal cost of ozone formation per metric ton of VOC and NOx emission using a multivariate transfer function is estimated using data obtained from Muller and Mendelsohn's (2007) US based analysis, as well as Muller's (2012) updated marginal societal cost values. This extends societal cost estimates beyond the US to give global coverage, providing an estimate of the societal cost of air pollution as a function of ambient O_3 concentration, local income, and local population density. As this provides a direct link between emissions and societal costs, it is not necessary to quantify environmental outcomes as an intermediate step.

    c) **Visibility impacts from the six primary pollutants:** The methodology to estimate the impacts on visibility is based on using a multivariate transfer function estimated using data obtained from Muller and Mendelsohn's (2007) US based analysis, as well as lead-author Muller's (2012) updated marginal societal cost values. The transfer function estimates the societal cost of air pollution as a function of ambient O_3 concentration, local income, local population density, temperature, and rainfall. Reductions in the level of air pollutants - particularly fine particulate matter, improve visibility, leading to physical and economic benefits in both recreational and residential settings.[10] The societal cost of air pollution's impact on visibility is estimated directly from emissions using function transfer (described below) in a single step without intermediate estimates of environmental outcomes.

d) **Agricultural impacts from NOx and VOCs:** The societal cost of air pollution's impact on agriculture is estimated directly from emissions using value transfer. The approach to transfer the damages per metric ton for NO_x and VOC for agriculture is to adjust the societal costs provided by Muller (2012) for GNI (PPP) to account for differences in purchasing power. A linear relationship is assumed between the social cost, GNI (PPP) and emissions.

[10] Industrial Economics (2011). Health and Welfare Benefits Analyses to Support the Second Section 812 Benefit-Cost Analysis of the Clean Air Act. Final Report for the US Environmental Protection Agency.

5 Future Development

53. The Interim Air Pollution Methodology represents the current state of knowledge on understanding air pollution impacts and builds upon decades of rigorous scientific work. But some opportunities for improvement exist including enhancing air pollution data accounting across the value chain and further development of the valuation of impacts.

54. Opportunities to further advance air pollution impact accounting include:

    a) Improvements in data quality for air pollution accounting. As the desire and expectation to measure air pollution increases, there will be expansions of techniques for determining pollutant emissions and the number of entities conducting air pollution accounting.

    b) Increased public disclosure of air pollution data to support the development of air pollution impact accounts. Increased use of reporting standards and disclosure frameworks will augment the availability of value chain air pollution impacts. Moreover, leveraging crowdsourced and citizen science data to supplement traditional data sources and improve spatial and temporal coverage could be a promising opportunity, potentially providing real-time, localized information on air quality and health impacts, thereby enhancing data coverage and accuracy.

    c) Expanding the impact calculations, currently focused on meteorological data from capital cities, to include meteorological data for additional locations within each country. Future work diversifying input data from different geographical locations and city types can provide a more representative and accurate assessment of air pollution impacts within and across countries.

    d) Refining health impact valuation methods could lead to the incorporation of a wider range of health outcomes and demographic factors. Expanding the set of health outcomes included in impact calculations to cover conditions like cardiovascular diseases, neurological impacts, mental health and/or the health impact of indoor VOCs, can improve the accuracy of health impact valuations.

    e) Some studies have indicated that certain age groups, particularly the elderly and young, may be more susceptible to the health impacts of air pollution. This method does not break down the exposed population by age demographics because consistent international data are not available. This is aligned with the approaches described by Industrial Economics (2011) in their analysis of the US

Clean Air Act and in Ostro's (1994) methodology review[11]. However, further academic research and/or methodological development, including using demographic data to account for variations in susceptibility and exposure across different population groups, may improve the accuracy of impact measurement.

f) Development in the approach to measuring secondary health, visibility, and agricultural impacts such as methods incorporating detailed process-based models that account for the complex interactions between pollutants, environmental conditions, and economic outcomes. This can include leveraging advanced atmospheric chemistry models to simulate the formation and dispersion of secondary pollutants like ozone, utilizing high-resolution meteorological and land-use data to capture the spatial variability in visibility impacts, and incorporating dynamic crop yield models that consider factors such as soil health, water availability, and adaptive farming practices. By combining these models with local and regional data on demographics, economic activities, and health outcomes, a more nuanced and accurate assessment of the societal costs of air pollution could be created. Such methods could also look to provide detail on additional impacts, such as the health impact of indoor VOCs or the impact of visibility on tourism. However, the materiality of such secondary health, visibility, and agricultural impacts to the overall impact of air pollution across all countries ought to be considered before such development takes place.

g) The consideration of additional impacts, such as those on tourism, ecosystem services would improve the completeness of the Methodology further.

55. Further revisions based on these opportunities, among others, will be considered as the Methodology is further developed and revised through the Due Process Protocol according to the established annual VTPC work plan.

[11] Industrial Economics (2011). Health and Welfare Benefits Analyses to Support the Second Section 812 Benefit-Cost Analysis of the Clean Air Act. Final Report for the US Environmental Protection Agency.

Appendix A: Glossary

Term	Definition	Source[12]
Cost of illness (COI)	A calculation of the total economic impact of a disease or health condition, including the direct costs of medical treatment and the indirect costs of lost productivity/income.	US CDC
Direct operations/ Operational processes (gate-to-gate)	Covers activities over which the business has direct operational control, including majority owned subsidiaries.	Natural Capital Protocol
Disability-adjusted life year (DALY)	One DALY represents the loss of the equivalent of one year of full health. DALYs for a disease or health condition are the sum of the years of life lost to due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population.	World Health Organisation
Downstream processes (gate-to-grave)	Covers activities linked to the purchase, use, re-use, recovery, recycling, and final disposal of the business' products and services.	Natural Capital Protocol

[12] Some definitions are adapted from the original source.

Ecosystem services	The benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling.	Millennium Ecosystem Assessment
Environmentally extended input output models	An analytical framework that incorporates environmental data into economic input-output models to assess the environmental impacts of economic activities	UNEP
Impact	A change in one or more dimensions of people's well-being directly or through a change in the condition of the natural environment.	GM1
Impact accounting	A system for measuring and valuing the impacts of corporate entities and generating impact information to inform decisions related to an entity's effects on sustainability.	GM1
Impact drivers	Refers to the sequence of an entity's inputs and outputs	Impact Management Platform (GM1)

	that may have positive and/or negative impacts on people's well-being.	
Impact pathway	The series of consecutive, causal relationships, ultimately starting at an input for an entity's activities and linking its actions with related changes in people's well-being.	ISO 14008:2019 (GM1)
Input	The resources and business relationships that the entity draws upon for its activities.	Impact Management Platform (GM1)
Lagrangian puff air dispersion model	A type of atmospheric dispersion model that simulates the transport, dispersion, and transformation of pollutants in the air by representing them as a series of discrete "puffs" that move and expand in response to wind and atmospheric conditions.	European Environment Agency (EEA)
Linear dose-response function	A model that describes the relationship between the dose of a substance and the magnitude of the response, assuming that any increase in dose results in a directly proportional increase in response.	World Health Organisation (WHO)
Multivariate transfer function	A mathematical model used to describe the relationship between multiple input	European Commission

	variables and multiple output variables, accounting for the dynamic interactions between them.	
Monetized impact	The process of assigning monetary values to damages.	N/A
Outcome	The level of well-being experienced by people or condition of the natural environment that results from the actions of the entity, as well as from external factors. Outcomes are used to describe the one or more dimensions of people's well-being that are affected by an input, activity, and/or output.	Impact Management Platform (GM1)
Output	The direct result of an entity's activities, including an entity's products, services, and any by-products.	Impact Management Platform (GM1)
Primary pollutants	Substances directly emitted from a source, such as vehicles or industrial facilities, that are harmful to health or the environment, including pollutants like carbon monoxide, sulfur dioxide, and particulate matter	US EPA
Secondary pollutants	Pollutants not directly emitted, but formed in the atmosphere through	US EPA

	chemical reactions between primary pollutants and other atmospheric components, such as ozone and secondary particulate matter	
Stakeholders	Stakeholders are defined as those who can affect or be affected by the entity.	European Sustainability Reporting Standards (GM1)
Upstream processes cradle-to-gate)	Covers the activities of suppliers, including purchased energy.	Natural Capital Protocol
Value factor	A value factor translates the information that an entity collects across its operations into insights on the relative importance, worth, or usefulness of an impact.	Value Commission (GM2)
Value of a statistical life	The amount individuals would be willing to pay or to accept to experience small changes in mortality risk, aggregated to estimate the monetary value of a reduction in mortality risk of 100%.	US EPA
Value transfer	The process of estimating economic values for ecosystem services or other non-market goods by transferring existing benefit or cost estimates from studies already completed in one location or context to	Organisation for Economic Co-operation and Development (OECD)

	another, different but similar, location or context.	

Appendix B: Methodological Details

B1. Four categories of value factors were developed to determine air pollution impacts: health impacts from primary pollutants, health impacts from secondary pollutants, Visibility and Agriculture. For each category, a wide array of approaches was considered ranging from techniques in the academic and business literature to methods developed internally. The value factors presented considered the valuation techniques, the recency of the underlying data, the spatial extent and resolution, the physical or socioeconomic sophistication in the underlying models, and the assumptions made in each step.

B2. The details of how each value factor is determined can be found in the sections below.

Detailed methodology for Impacts on Health from Primary Pollutants

B3. To determine the monetary cost of primary health impacts, the calculation begins with quantifying the change in human health and multiplying it with the cost of a specific health impact such as a chronic disease or premature mortality.

Quantifying environmental outcomes

B4. The changes in human health are calculated by running a Lagrangian puff air dispersion model to determine change in pollutant concentrations over a specified area. The dispersion model considers local meteorological conditions, as well as the persistence in air of pollutants in estimating the dosing. Finally, an estimate of the number of people affected is produced by overlaying a population grid describing the demographics in the location of interest.

B5. As air pollution is a local impact principally impacting those near the pollution site, value factors for specific countries are particularly important. The first step involves representing the local region in the model (e.g., its population density and meteorological conditions).

B6. Each modelled location is represented using a grid which corresponds to the geographical extent of the analysis. The maximum geographical region that ATMOS 4.0 can model is 2.5 degrees latitude (approximately 250 km) by 2.5 degrees longitude (ranging from 0km at the poles to 250km at the equator), with grid squares of a maximum size of 0.1 degrees latitude by 0.1 degrees longitude. For the analysis presented here a default of 50 km by 50 km is used as this allows a 'square area' to be consistently selected.

Meteorological conditions

B7. The dispersion of pollutants is highly dependent on the weather conditions surrounding the pollutant source. The ATMOS 4.0 model is used to estimate how pollutants disperse and how concentrations of the pollutant change in the areas surrounding the pollutant source. The model uses four data points a day for 365 days: 12am, 6am, 12pm and 6pm. Each data record includes mixing height, wind speed, wind direction and precipitation, all of which influence pollutant dispersion.

B8. Meteorological data are collected on a consistent basis globally and the data required are available for most global locations through public sources online and are described in Table 1. Data from the nearest monitoring station to capital city of each country and US State has been selected.

Data input	Description	Source
Wind speed (m/s)	The rate at which air is moving horizontally past a fixed point. To address gaps, hourly wind speed readings are used to produce a six-hour moving average for each data point in each month for the latest 5 years of data from the monitoring station. For additional gaps in the data a monthly average speed is used. When gaps in wind speed data for a monitoring station exceeds 40% of data points needed regional average speeds are calculated using existing data.	National Oceanic and Atmospheric Administration (NOAA) 2024
Wind direction (degrees)	The compass direction from which the wind is blowing. As with wind speed, average data is calculated for each datapoint. For additional gaps in the data a monthly average direction is used. Regional average wind directions are used when monitoring station specific gaps were greater than 40% of data points needed	NOAA 2024
Precipitation (mm)	Rainfall from the atmosphere to the ground.	NOAA 2024

	Average monthly precipitation and average number of days of precipitation per month are used for each location. To estimate hourly rainfall, the average monthly rainfall is divided by the number of days of precipitation in that month and then divided by 24. Average hourly precipitation is assigned to each data point for the number of days of precipitation in each month. For example, if there are 15 days of precipitation in January then the average hourly precipitation will be assigned for all 4 data points for the first 15 days of January with the remaining 16 days are assigned a zero. This gives the most realistic account of the precipitation profile of a month where daily precipitation data are not available.	
Mixing height (m)	The altitude in the atmosphere up to which pollutants and other atmospheric constituents are mixed vertically. Two observations of mixing height each month are taken: one at midnight and one at midday. The midnight reading is also used for the 6am data point and the midday reading is used for the 6pm data point. These values are repeated for each day in the month. This approximation is used because of the lack of readily available hourly data that can be used to derive mixing height.	NOAA 2024

Table 1: Meteorological data inputs overview

B9. To assess the impact on the human population of each pollutant, the number and distribution of people living around the pollutant source is required. The aim is not to establish the population distribution for a specific location, but to establish a representative population distribution for the purpose of estimating national-level population exposure to pollutants in a simplified manner.

B10. This methodology determines representative population distributions as a function of the urban population density, rural population density and percentage of people living in cities with a population greater than 1 million.

B11. The model uses three different stylized urban population distributions which have different total populations contained within them. The total population of each city determines which distribution is selected. In addition, a rural distribution is defined to understand how emissions would differ when populations are not concentrated in the center.

B12. To account for different emitting activities the model uses three different pollutant emissions grids which locate the source of emissions in different positions.

B13. Differentiated estimates for three types of stationary source were created: urban, peri urban and rural; and two types of mobile source: urban transport and rural transport.

Urban

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0
0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Peri urban

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Transport

0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Diagram 1: Pollutant emission grids

B14. A source-receptor transfer matrix (SRTM) is the output of the ATMOS 4.0 model. The SRTM specifies the change in air pollution concentration in each grid square based on the emissions from the source square(s). The model calculates this based on the meteorological conditions and deposition rates (wet and dry) of particulates. Any increase in emissions in a particular source cell increases the concentration in a receptor cell linearly –the SRTM Is calculated for one kg of pollutant and multiply the results by the quantity of emissions in each location.

B15. Dispersion of primary pollutants $PM_{2.5}$ and PM_{10} is calculated based on the quantity of emissions, their location and meteorological information. For the secondary pollutants of NO_x, SO_2 and NH_3, the model first calculates the amount of secondary pollutant formed and then models the dispersion in the same way as $PM_{2.5}$.

B16. The quantity of secondary pollutants from NO_x and SO_2 is determined by their reaction with available oxygen. This is a non-linear photochemical process which is highly dependent on local conditions and is subject to seasonal variations[13]. As recommended by the Sim-Air model, a constant reaction rate from primary to secondary pollutants and rates for dry and wet deposition are applied. This is also in line with the approach taken by ExternE (2005), Muller and Mendelsohn (2007) and others.

B17. For NH_3, the main pathway to human health impacts is through NH_4 (which contributes to $PM_{2.5}$) formation, through reactions with SO_x and NO_x already in the atmosphere. The model first estimates NH3 deposition and the reactions to form NH_4, before calculating the dispersion in the same way as $PM_{2.5}$. The rate of deposition and fraction which forms NH_4 varies by region, local canopy cover and weather conditions. A range of deposition values have been recorded: Loubet et al. (2006) estimates between 40% and 98% are deposited within 2km[14]. A 70% deposition rate is used as the default value, and where the local average deposition rate is known this can be used.

B18. The SRTM is then multiplied by emissions from source to evaluate change in concentration.

B19. To calculate the change in concentration of pollutant (i.e. dose), measured in mg/m^3 across the grid, the SRTM is multiplied by the emissions within the grid outlined in Step 2.

Value societal impacts

B20. To value the impact of the environmental changes for this impact pathway, the harm to health from increased pollutant concentrations is assessed first and then this harm is valued.

B21. Dose-response functions from published academic literature and government air quality cost benefit analysis are used to estimate how the changes in pollutant concentrations, affect human health. Dose-response functions describe how the number of health outcomes (responses) change with increasing concentrations of air pollutants (doses).

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[13] Khoder, M.I. (2002). Atmospheric conversion of sulfur dioxide to particulate sulfate and nitrogen dioxide to particulate nitrate and gaseous nitric acid in an urban area.

[14] Loubet, B., et al (2006) Ammonia deposition near hot spots: processes, models and monitoring methods. Background Document for Working Group 3: UNECE Expert Workshop on Ammonia, Edinburgh 4-6.

B22. The societal cost of the health outcomes quantified above are valued using estimates of willingness to pay (WTP) for health and life. There are alternative approaches to this valuation including the Cost Approach, however WTP is judged to be the most complete valuation approach.

B23. WTP values for health and life are widely used in public policy decision-making. For the Methodology, WTP valuations are selected from the OECD, which were derived from a meta-analysis of studies in many countries.[15]

B24. Between two thirds and three quarters of the health costs of air pollution are attributable to premature mortality[16]. Of the six emissions considered in this paper, two are directly associated with premature mortality: SO_2 and $PM_{2.5}$. $PM_{2.5}$ consists of both primary $PM_{2.5}$and secondary $PM_{2.5}$ formed from reactions of NO_x, NH_3, SO_2 and other gases in the atmosphere. Hence the contribution to premature mortality of $PM_{2.5}$, NO_x and NH_3 can be quantified using a response coefficient for $PM_{2.5}$, as can part of the contribution of SO_2. SO_2 is also directly associated with premature mortality independent of its role in $PM_{2.5}$ formation and this affect is quantified using an SO_2 specific response coefficient. Consistent with academic research (Muller and Mendelson, 2007) PM_{10} is assumed not to contribute directly to premature mortality.

B25. For morbidity impacts, this methodology focusses on chronic bronchitis (PM_{10}), restricted activity days (RAD) ($PM_{2.5}$) and respiratory hospital admissions (SO_2). Chronic bronchitis is typically the most material of these, while RADs and respiratory hospital admissions are broad categories to capture many of the short-term health ailments associated with these pollutants. While the literature notes there is uncertainty as to the precise cause-effect relationships between each pollutant and specific health outcomes, these outcomes are typical[17].

B26. Linear dose-response coefficients originally published in peer reviewed academic literature which have subsequently been applied by international institutions are used. This approach is consistent with that taken by, for example, by Defra[18]. These are listed in Table 2.

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[15] Organisation for Economic Co-operation and Development (OECD). (2010). *Environmental policy and household behaviour: Sustainability and consumption* (ENV/EPOC/WPNEP(2010)9/FINAL) . https://one.oecd.org/document/ENV/EPOC/WPNEP%282010%299/FINAL/en/pdf

[16] See the following studies: OECD 2009, Muller and Mendelson 2007.

[17] See the following studies: Ostro 1994, and ExternE's 2005.

[18] Defra (2023) *Air quality appraisal: Impact pathways approach*. GOV.UK. https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-impact-pathways-approach#dispersion

Pollutant	Health endpoint	Value	Unit	Source
SO_2	All-cause mortality	0.6%	Percentage change in mortality rate per 10 ug/m3 change in pollutant concentration	Defra (2023)
$PM_{2.5}$	All-cause mortality	8%	Percentage change in mortality rate per 10 ug/m3 change in pollutant concentration	Defra (2023)
$PM_{2.5}$	Restricted activity days	0.0902	Percentage change in odds ratio per 10 ug/m3 change in pollutant concentration	Ostro (1987) and Ostro and Rothschild (1989)
PM_{10}	Chronic bronchitis	*0.0000265*	Percentage change in odds ratio per 10 ug/m3 change in pollutant concentration	Hurley et al (2005)
SO_2	Respiratory hospital admissions	0.50%	Percentage change in disease incidence per 10 ug/m3 change in pollutant concentration	Defra (2023)

Table 2: Dose response coefficients

B27. The OECD estimates of WTP for mortality endpoints are used.

B28. The EEA estimates of external costs of industrial air pollution for chronic bronchitis and restricted activity day morbidity endpoints are used[19].

B29. The calculation for the change in mortality for pollutant p:

[19] European Environment Agency. (2011). *Technical note: Estimating the external costs of airborne pollution in Europe*. https://www.eea.europa.eu/publications/the-cost-to-health-and-the/technical-note_estimating-the-external-costs/view

$$Total\ societal\ cost\ of\ mortality_p = VSL \times Change\ in\ mortality_p$$

B30. For morbidity, the total societal cost is calculated in the same way with WTP for each type of morbidity i applied to each pollutant p:

$$Total\ societal\ cost\ of\ morbidity_{pi} = WTP_i \times Change\ in\ morbidity_{pi}$$

B31. The total cost is obtained by summing the cost across all pollutants for mortality and all types of morbidity.

Key assumptions

B32. The primary health module for assessing air pollution impacts relies on several high-level assumptions. It uses a Lagrangian puff air dispersion model to estimate changes in pollutant concentrations, considering local meteorological conditions and pollutant persistence. It also assumes that it is appropriate to determine population exposure through overlaying a standardized demographic grid on the affected area. In addition, health outcomes are estimated using dose-response functions, with morbidity valued through Willingness to Pay (WTP) estimates and mortality through the value of a statistical life (VSL), based on OECD estimates from 366 studies[20]. It is assumed that these values are globally applicable. The ATMOS 4.0 model is preferred for its suitability for company-level applications and its ability to provide more accurate outcomes than assuming all impacts are local.

B33. Linear dose-response function: Linear functions are derived from epidemiological studies. They assume that emission concentrations are already above any damage threshold such that any addition of pollution in the environment causes an impact. This can over-estimate impacts at low levels if the ambient level is below the threshold at which they are harmful. However, in most industrial locations this is not the case[21]. Linear functions are widely applied in the literature because location specific functions would require detailed data on ambient concentrations around the world.

B34. Dose-response functions can be applied on a global basis: Dose-response functions are mostly estimated based on data from the United States, United Kingdom and Canada. These are routinely applied internationally and at different geographical scales where more precise data are unavailable. ExternE (2005) notes that there are too few studies

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[20] Organisation for Economic Co-operation and Development (OECD). (2010). *Environmental policy and household behaviour: Sustainability and consumption* (ENV/EPOC/WPNEP(2010)9/FINAL) . https://one.oecd.org/document/ENV/EPOC/WPNEP%282010%299/FINAL/en/pdf

[21] ExternE, (2005). Externalities of Energy: Methodology 2005 Update.

outside of Europe and North America to derive a robust relationship, and therefore recommend European and North American values are used elsewhere.

Limitations

B35. A key limitation of the approach adopted within this model stems from the estimation of meteorological conditions. The data has a number of gaps which have been filled using estimates, and the results are sensitive to the meteorological input conditions.

B36. City-type emission source grids represent another limitation within the Methodology. The differentiation between urban, peri-urban, and rural emission sources is a simplification that may not accurately capture the complexity of emission sources and their interactions in real-world scenarios.

B37. Similarly, population distribution categories (urban, peri-urban and rural) may not accurately reflect population distribution, as there can be significant variation within these categories but within a country and internationally. In addition, micro-scale variability, for example populations living near major roads, is also overlooked. These generalizations may lead to either an underestimation or overestimation of the number of people exposed to harmful pollutant levels.

B38. Moreover, the morbidity impacts captured within the Methodology are limited – inclusive only of chronic bronchitis, restricted activity days, and respiratory hospital admissions. This may overlook other significant health outcomes associated with air pollution, which include but are not limited to: cardiovascular diseases,[22] respiratory diseases beyond chronic bronchitis,[23] cancer,[24,25] adverse pregnancy outcomes,[26]

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[22] Zhang, Z., et al., "Long-term Exposure to Ambient Air Pollution and Risk of Cardiovascular Disease," *Journal of the American College of Cardiology*, 2021.

[23] Guarnieri, M., & Balmes, J. R. (2014). "Outdoor air pollution and asthma." *The Lancet*, 383(9928), 1581-1592.

[24] Loomis, D., et al. (2013). "The carcinogenicity of outdoor air pollution." *The Lancet Oncology*, 14(13), 1262-1263.

[25] Raaschou-Nielsen, O., et al., "Air Pollution and Lung Cancer Incidence in 17 European Cohorts: Prospective Analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE)," *The Lancet Oncology*, 2019.

[26] Pedersen, M., et al., "Association Between Maternal Exposure to Air Pollution and Birth Outcomes in Nine Countries: A Meta-Analysis," *Environmental Health Perspectives*, 2018.

neurological impacts,[27] mental health.[28] Therefore, the actual health impacts of air pollution may be higher than the Methodology suggests.

B39. For some countries, the Value Factors calculated are particularly low or particularly large, this is driven by the model's sensitivity to meteorological data, which is also prone to uncertainty. To overcome the outlier values, the final Value Factor coefficients have been capped at a minimum value set at the 30th percentile and the maximum value set at the 90th percentile. Values between the 30th and 90th percentiles are scaled within that range, based on their distance from the maximum and minimum for all countries / US States, with the median kept constant.

Detailed methodology for impacts on health from secondary pollutants

B40. Secondary pollutants are not subject to dispersion modelling in our approach.

B41. Ozone is not typically emitted directly by companies. Rather, it is formed through a photochemical reaction between VOCs, NO_x, and CO. This is highly dependent on specific atmospheric and weather conditions. It is beyond the scope of the ATMOS 4.0 and Sim-Air models to simulate secondary pollutant formation as it only models linear secondary pollutants and physical dispersion. Instead, the societal cost of ozone formation per metric ton of VOC and NO_x emission is estimated using a multivariate transfer function estimated using data obtained from Muller (2012). As this provides a direct link between emissions and societal costs, it is not necessary to quantify environmental outcomes.

B42. The underlying principles of the valuation of mortality and morbidity are the same as indicated above for primary pollutants. However, the difficulty of modelling ozone formation directly makes it necessary to directly estimate societal costs from the quantity of pollutants emitted. Therefore, societal cost estimates from Muller and Mendelsohn's (2007, 2009, 2011) peer reviewed studies are used to derive multivariate functions from their data, and these are transferred to other countries. Muller and Mendelsohn's analysis provides US county-level societal cost estimates by multiplying the proportion of people at risk by the predicted ambient concentrations to estimate exposures. Per metric ton values for the secondary ozone effects from NO_x and VOCs provided from the APEEP model are used to estimate transfer functions for mortality and morbidity. An updated version of this analysis (Muller 2012) is summarized in Table

[27] Block, M. L., & Calderón-Garcidueñas, L. (2009). "Air pollution: Mechanisms of neuroinflammation and CNS disease." *Trends in Neurosciences*, 32(9), 506-516.

[28] Braithwaite, I., et al., "Exposure to Air Pollution and Risk of Depression and Anxiety: A Systematic Review and Meta-Analysis of Epidemiological Studies," *Environmental Research*, 2019.

3. These values are based on a random sample of 346 (ten percent of the counties used in his original model).

Pollutant	Mortality	Morbidity
NOx	*321.72*	*5.09*
VOC	*145.70*	*2.27*

Table 3: Updated societal cost per tonne (USD 2011)

B43. This dataset of cost estimates and contextual data by US county is used to estimate functions to transfer the societal costs of these impacts to different countries

B44. Guided by Muller's input and using his dataset (Muller, 2012), the Methodology uses multiple robust OLS regressions to estimate societal cost from morbidity and mortality per metric ton of each pollutant as a function of population density, median income, and ambient ozone concentration for the US counties covered. All variables are log-transformed to allow easy interpretation of the coefficients by taking the natural logarithm (ln) of each. This means that each coefficient approximates the percentage change in the dependent variable (societal cost) associated with a one percent change in each independent variable (population density, median income, and ambient zone concentration.

B45. Table 4 reports the estimated coefficients for each robust OLS function. The R^2 value shows the percentage of the variance in the dependent variable (societal cost) that is explained by variance in the independent variables.

	Population density (β_1)	Median income ($\beta 2$)	Ambient ozone concentration ($\beta 3$)	Constant (α)	R^2
Mortality					
NO_x	0.2512566	0.647753	0.8854066	-0.038998	0.57

VOC	0.4457388	0.602483	1.117034	-0.757889	0.70
Morbidity					
NO_x	0.1999747	0.7138054	0.910492	-4.511353	0.58
VOC	0.3803628	0.6922578	1.082016	-5.559508	0.71
Note: All equations are estimated using robust OLS in a log-log form.					

Table 4: Estimated coefficients for secondary health impact

B46. The three explanatory variables cover the main drivers of ozone impacts on mortality and morbidity:

a) Population density is a proxy for the number of people likely to be in contact with the pollutant.

b) Median household income is proxy for the impact of budget constraints on people's WTP to avoid the adverse health impact of air pollution.

c) Ambient ozone concentration reflects the fact that the impact of additional ozone depends on the absolute level of ozone in the atmosphere at a given location. While this function does not directly account for meteorological factors which affect the dispersion of pollution, the ambient ozone concentration will provide an indirect indication of this because where meteorological factors are such that pollution disperses the ambient concentration of ozone will be lower.

B47. To apply the transfer function, the coefficients are input to the general functional form in the form of the following equation:

$$\begin{aligned} ln\ (societal\ cost)_i \\ &= \alpha + \beta_1\ ln\ ln\ (population\ density)\ + \beta_2\ ln\ ln\ (median\ income) \\ &+ \beta_3 ln\ (ozone\ concentration) \end{aligned}$$

α, β_1, β_2, and β_3 are coefficients estimated by the regression

B48. Then, data on the population density, median income, and ambient ozone concentration are input to this function to calculate the societal cost of morbidity and mortality per metric ton of each pollutant.

B49. To calculate the total societal cost, the marginal societal costs - calculated using the above coefficients - are multiplied by the quantities of each pollutant released at each location for both mortality and morbidity. The sum of these gives the total societal cost.

B50. The calculation above is reliant on the use of five data sets:

a) Population density, used in estimating the transfer function. For country-level data this is sourced from the World Bank. For state-level data this has been sourced from the US Census.

b) Median income, used in estimating the transfer function. For country-level data this is sourced from the World Bank. For state-level data this has been sourced from the US Census.

c) Ambient ozone concentration, used in estimating the transfer function.

B51. The underlying willingness to pay (WTP) estimates of health and life are different in the Muller and Mendelsohn study. This is because they use US derived estimates of 'cost of illness' rather than WTP. To ensure consistency with the WTP values applied for the VSL and morbidity events in the other parts of the air pollution valuation approach, an adjustment is made to these figures.

Key assumptions

B52. Two key assumptions are made in the Methodology. Firstly, that population density, median income and ozone concentration are the primary determinants of health impacts from NO_x and VOCs via ozone. These three variables represent differences in the propensity for emissions to have impacts (due to ambient pollution levels), the probable scale of the impact (based on the number of people that could come into contact with the pollution) and the value of impacts (which is affected by income). The impacts of weather on dispersion are implicitly represented within the ambient pollution level variable.

B53. Secondly, this approach assumes that it is appropriate to transfer a relationship derived in the US to other countries. While the variation within the US is less than that between the US and other countries, it is considered an acceptable approximation in the absence of better data. The relatively low materiality of these health impacts compared with those calculated in the previous section further justify this approach.

Limitations

B54. Limitations of this approach stem from the lack of direct dispersion modelling for secondary pollutants. Simplifying the process of secondary pollutant formation, particularly ozone, may overlook crucial variables and not fully capture the complexities of secondary pollutant formation and dispersion.

B55. The Methodology uses population density, median income, and ambient ozone concentration as primary determinants of health impacts. While these are significant factors, they do not capture the full range of variables that can influence health outcomes, such as healthcare access, baseline health conditions, and specific vulnerability of certain populations[29]. Moreover, the resolution of the data input for ozone data may not fully capture the spatial variability of ozone, which can be significant over small distances[30].

B56. The Methodology is limited by data availability. Where one, or more, data inputs are missing for a country, we have assigned the regional average value coefficient. If regional averages were not able to be calculated due to missing data inputs across constituent countries, we have instead assigned the average value coefficient for the country's income class – as defined by the World Bank.

B57. The Methodology adjusts the cost estimates from the Muller and Mendelsohn study to align with WTP values used in other parts of the air pollution valuation approach. This assumes that WTP for health and life is consistent across different regions and socio-economic context.

B58. This methodology does not attempt to quantify potential indoor health impacts of VOCs, which can often be higher than outdoor levels[31] and can have acute and chronic impacts on human health.[32]

Detailed methodology for impacts from visibility

B59. The societal cost of air pollution's impact on visibility is estimated directly from emissions using function transfer (described below) in a single step without intermediate estimates of environmental outcomes. The Methodology to estimate the impacts on visibility is also based on Benefit Transfer of Muller and Mendelsohn's (2007) US based analysis. The updated average of the marginal damage costs provided by

[29] Hajat, A., Hsia, C., & O'Neill, M.S. (2015). "Socioeconomic Disparities and Air Pollution Exposure: A Global Review." *Current Environmental Health Reports*, 2, 440-45.

[30] Fiore, A.M., et al. (2015). "Air Quality and Climate Connections." *Journal of the Air & Waste Management Association*, 65(6), 645-685.

[31] Wallace, L.A. (2001). "Volatile Organic Compounds and Health." *Journal of the Air & Waste Management Association*, 51(3), 214-247.

[32] Sundell, J. "Indoor air pollution and health: A comprehensive review of the effects of indoor air quality on human health," *International Journal of Environmental Research and Public Health*, 2017.

Muller (2012) is presented in the table below. Reductions in the level of air pollutants - particularly fine particulate matter, improve visibility, leading to physical and economic benefits in both recreational and residential settings (Industrial Economics, 2011).

Pollutant	Societal cost per tonne (USD, 2011)
PM2.5	*21.2*
PM10	*63.60*
SO2	*10.43*
VOC	*68.74*
NOx	*37.83*
NH3	*7.71*

Table 5: Updated societal costs of air pollutants due to reduced visibility per tonne emitted

B60. Muller and Mendelsohn (2007) use a model which describes the visual range in each county as a function of climatic and geographical factors and ambient concentrations of PM_{10}. They use a regression model to estimate the relationship between visual range while controlling for temperature, precipitation, latitude and altitude, Muller and Mendelsohn use contingent valuation (Chestnut and Rowe, 1990; Loehman and Boldt, 1990; McClelland *et al*., 1990). Muller and Mendelsohn use estimates of household WTP for incremental changes in visibility associated with recreation experiences and regional estimates from Chestnut and Dennis (1997) and McClelland *et al.* (1990).

B61. Benefit Transfer is the most practical method for estimating the societal cost of air pollution from reductions in visibility[33]. This is because there are no consistent primary studies estimating WTP to avoid reductions in visibility for specific locations across the global scale an E P&L is likely to cover, and conducting a new, primary study on this scale is not feasible (see above). Multivariate transfer functions, based on the key factors, are derived and applied as outlined by Muller (2012). The same approach as for secondary

[33] ExternE (2005) reports that "In the absence of a specific contingent valuation study for Europe aiming to elicit the average willingness-to-pay measure to improve visibility, some adjustment in the US numbers may be done to account for lower concern about visibility effects."

pollutant health impacts (previous sub-section) is followed. This produces the coefficients listed in Table 6.

Pollutant	Population Density (β1)	Median Income (β2)	Annual rainfall (β3)	Maximum temp (β4)	Ozone concentration (β5)	Constant (α)	R2
PM10	0.1638572	0.7953505	-0.3586976	1.178389	0.9080807	-6.437607	0.51
PM2.5	0.1638572	0.7953505	-0.3856976	1.178389	0.9080806	-7.536219	0.51
SO2	0.1075783	0.3053946	-0.4279365	1.204486	0.5226418	-2.27483	0.43
VOC	0.1629352	0.790523	-0.356439	1.17632	0.9080239	-8.489709	0.51
NOx	-0.1297407	0.3104432	0.5843402	0.027647	1.598195	5.382386	0.33
NH3	0.1955141	1.295007	-0.0186555	1.40217	0.8385865	-14.70028	0.27
Note: All equations are estimated using robust OLS in a log-log form.							

Table 6: Estimated coefficients for impact of reduced visibility

B62. To apply the transfer function, the coefficients in Table 6 are input to the general functional form given in the equation below. The same explanatory variables are used for each visibility transfer function to provide a simple and consistent approach, which also reduces the data burden of the analysis. Then, data for each variable (population density, etc.) are input to this function to calculate the societal cost of reduced visibility per metric ton of each pollutant.

$$
\begin{aligned}
ln\ (societal\ cost)_i \\
&= \alpha + \beta_1\ ln\ ln\ (population\ density)\ + \beta_2\ ln\ ln\ (median\ income)\ + \beta_3 \\
&\quad ln\ ln\ (annual\ rainfall)\ + \beta_4 \\
&\quad ln\ ln\ (average\ annual\ maximum\ temperature) \\
&\quad + \beta_5 ln\ (ambient\ ozone\ concentration)
\end{aligned}
$$

B63. To calculate the total societal cost, the marginal societal costs calculated above are multiplied by the quantities of each pollutant released at each location. The sum of these gives the total societal cost.

B64. The calculation above is reliant on the use of seven data sets:

a) Population density, used in estimating the transfer function. For country-level data this is sourced from the World Bank. For state-level data this has been sourced from the US Census.

b) Median income, used in estimating the transfer function. For country-level data this is sourced from the World Bank. For state-level data this has been sourced from the US Census.

c) Ambient ozone concentration, used in estimating the transfer function.

d) Annual rainfall, used in estimating the transfer function. For country-level data this is sourced from the World Meteorological Organisation. For state-level data, the US value from the country source has been used.

e) Maximum temperature, used in estimating the transfer function. For country-level data this is sourced from the World Meteorological Organisation. For state-level data, the US value from the country source has been used.

Key assumptions

B65. A key assumption of this methodology is that population density, medium income, annual rainfall, average annual maximum temperature, ambient concentration of O_3 are the primary determinants WTP for impacts on visibility. These variables represent: Differences in the propensity for emissions to have impacts (due to ambient pollution levels, temperature, rainfall); the number of people affected and the value of impacts according to people's budget constraints. Given this and the relatively high R^2 values for most pollutants, it is a reliable set of explanatory variables. The R^2 is lower for NO_x and NH_3, perhaps due to the nature of the chemical relationships. Given the low materiality of the absolute values, it is deemed a cause for concern for the interim methodology.

B66. A second key assumption is that it is appropriate to transfer a relationship derived in the US to other countries. In contrast, WTP for reduced visibility impairment may vary. ExternE (2005) noted that WTP in the EU was much lower than in the US. However, in the absence of better data to develop a more sophisticated function, this approach is considered an acceptable approximation, particularly given the materiality of the impacts relative to the societal costs of health impacts.

Limitations

B67. Limitations of this approach stem from the lack of direct dispersion modelling for secondary pollutants. Simplifying the process of secondary pollutant formation, particularly ozone, may overlook crucial variables and not fully capture the complexities of secondary pollutant formation and dispersion.

B68. The Methodology uses population density, median income, annual rainfall, average annual maximum temperature, and ambient ozone concentration as primary determinants of WTP for visibility impacts. While these variables are important, they do not capture the full range of factors that influence visibility and its valuation. This simplification may not account for other important factors such as local pollution sources, specific meteorological conditions, and land use patterns, which can all influence visibility. Moreover, the use of 11x11km grid resolution for the data input for ozone data may not fully capture the spatial variability of ozone, which can be significant over small distances.[34]

B69. The Methodology is limited by data availability. Where one, or more, data inputs are missing for a country, the regional average value coefficient was assigned. If regional averages were not able to be calculated due to missing data inputs across constituent countries, the average value coefficient for the country's income class – as defined by the World Bank was instead assigned.

B70. The Muller and Mendelsohn (2007) study uses willingness to pay estimates to determine the impacts of visibility on recreation and does not specifically assess the impact of visibility on tourism. Studies have shown that visibility can reduce tourist satisfaction, negatively impacting tourism revenues and repeat visitation rates,[35] especially international visitation rates.[36] This impact could potentially be significant for

[34] Fiore, A.M., et al. (2015). "Air Quality and Climate Connections." *Journal of the Air & Waste Management Association*, 65(6), 645-685.

[35] Li, H., et al. "The Impact of Air Pollution on Tourist Satisfaction: Evidence from China," *Journal of Sustainable Tourism*, 2016.

[36] Huang, J., & Xu, Y. "The Effect of Air Quality on Tourist Arrivals: Evidence from New York City," *Environmental Economics and Policy Studies*, 2019.

economies with high incomes from tourism and tourism-related activities. This methodology is not inclusive of all these potential impacts.

Detailed methodology for impacts on agriculture

B71. The impacts cover reduction in agricultural productivity. Due to the existence of robust damage values per metric ton of emissions and the complexity of primary estimation, societal costs are calculated in one step to cover the process from emission to environmental degradation to human harms to societal costs.

B72. The societal cost of air pollution's impact on agriculture is estimated directly from emissions using value transfer. Tropospheric ozone inhibits plant growth. As a result, VOC and NO_x emissions can result in reduced agricultural productivity.

B73. The Methodology for estimating the impacts of these emissions on agriculture are based on Muller and Mendelsohn's (2007) US analysis, as for other impact areas introduced above. The updated average marginal damage costs provided by Muller (2012) are presented in the table below:

B74. Muller and Mendelsohn's (2007) analysis uses a dose-response function from the National Crop Loss Assessment Network (Lesser et al. 1990). This expresses the change in yield as a proportion of the baseline yield. To derive the yield loss in absolute terms, they multiply the estimated response function by the baseline yield.

B75. They show that not all air pollutants covered in this methodology paper are harmful for crop production. The economic impact for agriculture is determined by the loss of crop output. This is measured as the change in production caused by a one metric ton increase in the level of pollutant relative to a baseline production level, multiplied by the average market price for the associated crops.

B76. The approach to transfer the damages per metric ton for NOx and VOC for agriculture is to adjust the societal costs provided by Muller (2012) for GNI (PPP) to account for differences in purchasing power, as described above. Econometric estimation of transfer functions was explored but variables with sufficient explanatory power to explain how crop yields varied with ozone were not found. Therefore, the simpler value transfer approach, as opposed to Benefit Transfer was applied.

B77. Muller and Mendelsohn's damage values for the impacts of a metric ton of air pollutants on agricultural productivity were leveraged.

B78. For individual countries, the transfer value was adjusted based in PPP using the ratio Gross National income.

B79. Once the metric data on emissions and country-adjusted damage values are calculated, estimating societal cost becomes straight forward arithmetic.

Key assumptions

B80. As above, a key assumption in this calculation is that it is appropriate to transfer values derived in the US to other countries. The impacts on agriculture are affected by many variables which cannot be adequately represented by a simple function. Given the low materiality of agriculture impacts on overall societal costs, a more detailed analysis is not considered appropriate at this stage and these values are accepted as an approximation.

B81. The key data input for this calculation is a GNI PPP index, which adjusts US values to other countries. This was calculated using 2021 World Bank Data.

Limitations

B82. The Methodology is a simplified approach, using a single calculation to estimate the agricultural impacts of air pollution. This approach might not capture the nuances of how different pollutants interact with various crops under diverse environmental conditions. In addition, this single-step calculation may not adequately account for regional differences in climate, crop types, farming practices, and economic conditions.

B83. Furthermore, the reliance on US-based analysis may not adequately reflect the specific conditions and agricultural practices in other countries. Factors such as local crop varieties, soil types, and climate conditions[37] can significantly influence the impact of air pollutants on agricultural productivity.

B84. The Methodology uses dose-response functions from the National Crop Loss Assessment Network (NCLAN) to estimate yield losses. These functions express the change in yield as a proportion of the baseline yield. Simplifying yield loss estimation to a dose-response function may not capture the complex interactions between multiple pollutants and their cumulative effects on crops.

B85. Finally, while adjusting for GNI (PPP) provides a more accurate economic context, it may still not fully capture the regional variations in agricultural productivity and market conditions. This adjustment assumes that economic differences are the primary drivers of variability in impacts, which may not always be the case.

[37] Van Dingenen, R., et al. (2009). "The Global Impact of Ozone on Agricultural Crop Yields under Current and Future Air Quality Legislation."

Appendix C: Value Accountability Framework – Value Factors

This Appendix presents the Interim Air Pollution Topic Methodology summarized in the form of the Transparency Report proposed by the Value Commission of the Capitals Coalition. Minor adaptations have been made to the report structure to align with the impact accounting methodology.

<table>
<tr><th colspan="3">Transparency Report – Value factors</th></tr>
<tr><td colspan="3">Title and version #: Interim Air Pollution Topic Methodology Value Factors, Version 1

Developed by: International Foundation for Valuing Impacts

Published and updated date: October 2024</td></tr>
<tr><td colspan="3">Unit: Value of primary and secondary health, visibility and agricultural impacts of six air pollutants - PM_{10}, $PM_{2.5}$, SO_2, NO_x, NH_3, and VOCs, $/metric ton emitted in any country in the world.</td></tr>
<tr><td colspan="3">Linkages to other value factors: This value factor is a complement to the public good, independent, impact accounting methodology developed by IFVI in partnership with the Value Balancing Alliance and can be combined or complemented with value factors from other topic methodologies. Related value factors include greenhouse gas emissions and waste disposal. The latter incorporates the impact of air pollutants emitted as a consequence of the combustion of waste at incineration sites.</td></tr>
<tr><th colspan="3">SCOPE OF VALUE FACTOR</th></tr>
<tr><td>Impact pathway scope</td><td colspan="2">1. The scope of the value factor includes air emissions of six pollutants - PM2.5, PM10, SO2, NOx, and NH3 – within the entities full value chain.

2. The value factor captures many impacts quantified by leading models and academic papers, while future work will continue to explore the valuation of additional impacts. The Methodology covers: primary health, secondary health, visibility and agricultural impacts

3. More detail about the impact pathway scope can be found in Section 1.4: Scope and Assumptions

4. Application of the Methodology by an entity is based on a materiality assessment as outlined by General Methodology 1: Conceptual Framework for Impact accounting.</td></tr>
<tr><th></th><th>ESTIMATING CHANGES IN WELL-BEING</th><th>ESTIMATING SOCIETAL IMPACTS</th></tr>
</table>

Approach and specificity	1. For primary pollutants, the ATMOS 4.0 Lagrangian puff air dispersion model is used to assess how emissions disperse in the atmosphere. This model uses meteorological data to estimate changes in pollutant concentrations. Dose-response functions from published academic literature and government air quality cost benefit analysis are used to estimate how the changes in pollutant concentrations, affect human health. 2. For secondary health and for visibility impacts, the societal cost is estimated using multivariate transfer functions derived from Muller and Mendelsohn's studies. For agricultural impacts, the Methodology uses value transfer, leveraging damage values per metric ton of emissions from Muller and Mendelsohn's US-based analysis, adjusted for differences in purchasing power across countries. 3. Present research has not yet captured all impacts on society and future work will continue to develop value factors for these impacts. 4. The Interim Air Pollution Methodology has data inputs for many countries, models impacts at the national level, and for the United States at state-level. If national level data was unavailable, regional averages were used. 5. Additional details about estimating changes in well-being can be found in Section 4.2: Outcomes and Impacts and Appendix B: Methodological Details.	1. The impact of changes in health outcomes due to primary pollutants are valued using the OECD's value of a statistical life, and an estimate of the value of a DALY based on this. Both are based on inferred WTP. 6. As a multivariate transfer function is used to estimate the impacts of secondary health, visibility and health impacts no further calculation is required. However, the value of secondary health impacts is given as a cost of illness figure. To align with primary health impacts this is converted to WTP figure. 7. Air pollution impacts can be highly localized. As specific air pollution data are hard to obtain, impacts have been averaged at a national, or regional level, where needed. 8. Additional details about estimating societal impacts can be found in Appendix B: Methodological Details.
Data inputs	1. Integrated Global Radiosonde Archive (IGRA), National Oceanic and Atmospheric Administration	12. World Bank 13. US Census 14. Air quality appraisal: Impact pathways approach, Defra

	9. WMO Climate Normals, National Oceanic and Atmospheric Administration 10. World Bank 11. US Census	15. Estimating the external costs of industrial air pollution: Trends 2012-2021, EEA 16. Muller N.Z. and Mendelssohn, R., (2007).
VIEWS OF AFFECTED STAKEHOLDERS		
Representation of stakeholders	17. As an interim methodology, these value factors have yet to undergo the Due Process Protocol of the official methodology, which includes additional stakeholder engagement and public comment.	
18. ETHICAL DECISIONS IN ESTIMATING SOCIETAL IMPACT		
Equity weightings and income adjustments	19. The societal impacts of air pollution use a global DALY value to ensure equity in consideration of impacts regardless of their location.	
Accounting for future impacts	20. N/A	
Other ethical considerations	21. N/A	
SENSITIVITY		
Sensitivity to key variables	22. Sensitivity analysis was carried out for three countries (United States, China and Nigeria). Full results in the table below.	

Variable	**Flex**	**Impact rating**	**US** (% change to overall cost)	**China** (% change to overall cost)	**Nigeria** (% change to overall cost)
Mixing Height	+10%	Med	-0.8%	-1.3%	-0.2%
Mixing Height	-10%	Med	0.9%	1.3%	0.1%
Wind speed	+10%	High	-12.8%	-7.8%	-2.0%
Wind speed	-10%	High	9.5%	11.3%	2.4%
Precipitation	+10%	Low	-0.3%	-0.2%	-0.1%
Precipitation	-10%	Low	0.3%	0.2%	0.1%
Population density	+10%	Med	2.6%	4.2%	<0.1%
Population density	-10%	Med	-2.6%	-4.2%	< -0.1%
Value of Restricted Activity Days	+10%	Low	0.5%	0.5%	0.6%
Value of Statistical Life	+10%	High	9.5%	9.5%	9.4%

Note: The sensitivity percentages presented above are for Urban PM2.5 health impacts only. The sensitivity for other pollutants (e.g. NOx) and locations (e.g. peri-urban) may be different. Restricted Activity Day and Value of Statistical Life sensitivities are applied to all countries, as these are cross-cutting assumptions. The other variables tested in the sensitivity analysis are only applied for a single country at a time (e.g. mixing height in China). For meteorological variables, the effect of a change is non-linear due to (1) population exposure to pollutants is non-linear with meteorological variables, and (2) the scaling factor used to treat outliers is non-linear with size of value factor.

Table 7: Sensitivity Analysis

Appendix D: Data Sources in the Interim Air Pollution Methodology

Data	Source [38]	Year
Lagrangian puff air dispersion model	ATMOS 4.0	2024
Population	US Census Data	2020
Chronic bronchitis in adults (original data)	EEA	2021
Restricted activity days (original data)	EEA	2021
Population concentration 1 (% ppl in cities>1m)	World bank	2023
Population concentration 1 (% ppl in cities>1m)	US Census Data	2023
Population concentration 2 (% living in cities)	US Census Data	2020
Urbanization	World Bank	2022
Urbanization	US Census Data	2020
Rural population	US Census Data	2020
GNI PPP index to US	World Bank	2021
GNI PPP per capita OECD members	World Bank	2023
GNI PPP per capita EU members	World Bank	2023
Land area	US Census Data	2010

[38] Sources are hyperlinked for your reference.

Urban land	World Bank	2013
Urban land	World Bank, US Census Data	2013/2010
Rural land	World Bank	2013
Rural land	World Bank, US Census Data	2013/2010
Capital city population	UN Population Division	2018
Capital city population	US Census	2024
Rainfall	World Meteorological Organisation	2020
Maximum temperature	World Meteorological Organisation	2020
Oxygen 3	Our World in Data	2015
Median income	Our World in Data	2015
Mortality	World Bank	2022
Population density (people/miles2)	World Bank	2021
Population density (people/miles2)	US Census Data	2020/2010

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