INTERIM METHODOLOGY

Air Pollution

Environmental Topic Methodology

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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:

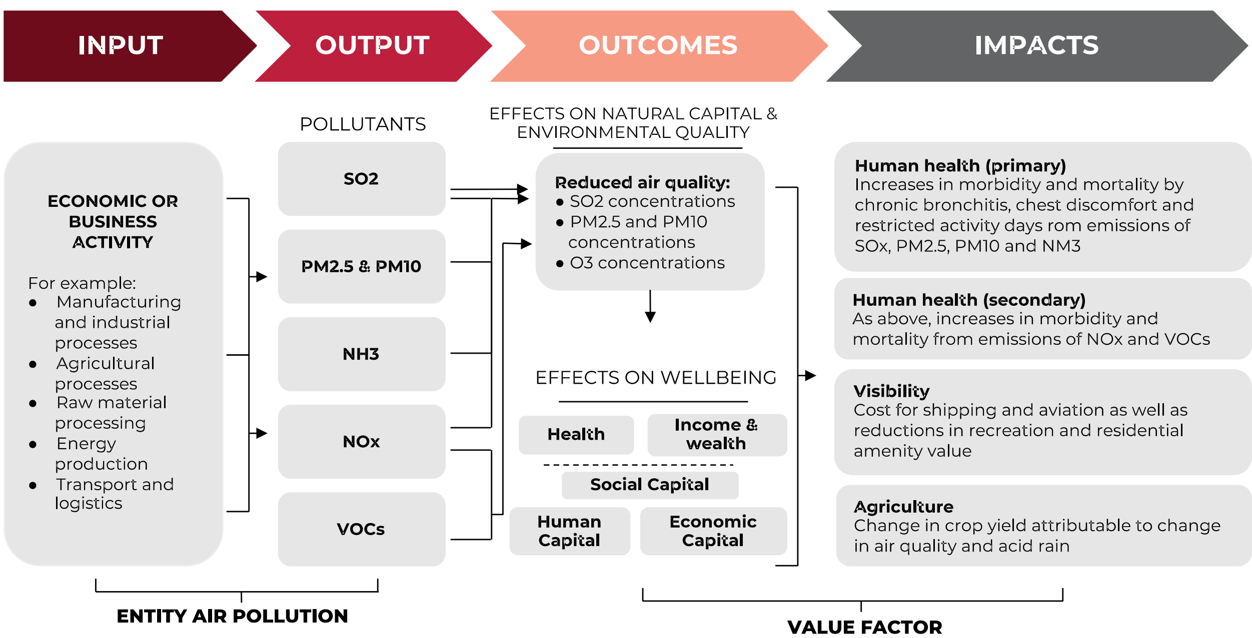

Figure 1: Air pollution impact pathway

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.

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[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

[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

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[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

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[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 ($\beta1$)	Median Income ($\beta2$)	Annual rainfall ($\beta3$)	Maximum temp ($\beta4$)	Ozone concentration ($\beta5$)	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

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[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.

Transparency Report – Value factors		
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*		
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.		
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.*		
SCOPE OF VALUE FACTOR		
Impact pathway scope	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.	
	ESTIMATING CHANGES IN WELL-BEING	**ESTIMATING SOCIETAL IMPACTS**

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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INTERIM METHODOLOGY

Land Use and Conversion

Environmental Topic Methodology

Table of Contents

Executive Summary

- The Interim Land Use and Conversion 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 Land Use and Conversion 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 land use and conversion across the entity's own operations as well as upstream and downstream in the value chain, considered separately;

  - categorize land use and land conversion per location and per type of land change

  - utilize the impact pathway and value factors developed in this methodology to convert land use and conversion 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 Land Use and Conversion 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 land use and conversion occur through changes in the provision of ecosystem services.

- **Section 3** establishes the data required from the entity to implement the Methodology. This includes land use and conversion in hectares, by location and land use type.

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

- **Section 4** outlines the approach of the Methodology for measuring and valuing the impacts, including identification of the value of ecosystem services and the nature of value lost through land change and conversion.

- **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 Land Use and Conversion (henceforth, the Interim Land Use 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 Land Use 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 Land Use Methodology can be used to inform internal decision-making, investment decisions, and understand the significance of waste 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 Land Use Methodology can be applied via this document and the Global Value Factors Database. Supporting resources include the Interim Land Use and Conversion Model and the Interim Land Use and Conversion 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 Land Use 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. Natural land areas, often rich in biodiversity, provide essential services to society, with changes to such environments negatively impacting society through economic, health and cultural losses. Healthy and biodiverse ecosystems provide essential services to society, such as regulating our natural environment, providing goods that support

livelihoods, offering opportunities for recreation and tourism, and providing cultural and spiritual enrichment.

8. Yet, 75% of the land-based environment has been significantly altered by human activities[2], with important social and economic implications for current and future generations. This decline in ecosystem functionality already costs the global economy more than $5 trillion in the form of lost natural services.[3]

9. Most corporate activities, from the goods that they procure to developments they enact, will have some impact on land. Food and agricultural processes drive more than 50% of the man-made pressure on biodiversity, with infrastructure and mobility responsible for a further 25%.[4] This methodology estimates the value of lost ecosystem services associated with the conversion and occupation of land and the associated lost ecosystem services that result from such activities.

10. The Interim Land Use Methodology takes a societal perspective and not the perspective of a discrete affected stakeholder group. By measuring and valuing the impacts on society, land use impact accounts can provide guidance to entities to manage and mitigate risks.

1.3 Key concepts and definitions

11. For the purposes of applying the Interim Land Use Methodology, the following terms are defined as:

    a) **Land use**: Broadly, land use is defined as land that is being used for production or industrial processes, which has been changed from the pristine land it would have been before human use. The land use value factors in this methodology specifically value the ecosystem services lost due to land use change in a given year (i.e., the difference in value between the ecosystem service provided by a pristine biome and a changed land use).

    b) **Land conversion:** Land conversion is the specific act of converting land from its pristine state to a state used for industrial or productive purposes. The land conversion value factors represent the total value of future lost ecosystem services as a result of conversion in the present year. This is seen as distinct from

[2] See IPBES (2019).

[3] See Boston Consulting Group (2021).

[4] See Boston Consulting Group (2021).

the land use value factors as the use factors represent opportunity cost in a given year, whereas conversion is over multiple years.

c) **Biome:** An area that is classified according to its temperature range, species type, and amount of water and light received[5]. The six biomes used in this methodology are: Tropical Forests, Temperate / Boreal Forest, Grasslands, Desert / Arid Grassland, Inland Wetlands and Coastal Wetlands.

d) **Pristine state:** An environmental state that has received no anthropogenic interference, or in other words, humans have not affected the condition of the environment.

e) **Ecosystem services:** The benefits that ecosystems provide to humans, directly and indirectly, that contribute to the quality of life and well-being. Ecosystem service values differ between biomes and are used to quantify the 'value' of impact when ecosystem services are lost in conversion from pristine lands.

1.4 Scope and assumptions

12. The Interim Land Use Methodology distinguishes between use (occupation) of already-converted land and new conversion of natural ecosystems.

    a) **Land use:** The land use value factors are used in cases where entities are occupying land but conversion of that land has occurred. This land likely was previously converted, but the conversion was not attributable to the entity. Any raw materials that are being extracted from a managed land, or footprint of buildings, of the entity could be captured with these value factors.

    b) **Land conversion:** The land conversion value factors are used in cases where land has been converted from natural land into managed land and attributed to the entity. Land conversion assesses the total impact, in lost ecosystem services, of that converted land, discounted to net present value (NPV).

[5] See National Geographic Society – Biomes (2024).

Box 1: Illustrative difference between land use and land conversion

Figure 1 illustrates the conceptual difference between land use and land conversion. The first column shows the total ecosystem service value provided by 1 ha of natural land, for example, a tropical rainforest. This land is converted in Year 0 to, say, a field of wheat, and the entity then uses that land to harvest wheat in Year 1. The difference between the ecosystem services the pristine land provided, and the converted land now provides, is the land use value factor. The land use value factor represents the opportunity cost of using the land as a field of wheat instead of a tropical rainforest in that given year.

The land conversion factor represents the total value of ecosystem services lost until that area of land could theoretically provide the pristine state ecosystem services again. In other words, the entity responsible for the conversion is consequently responsible for the loss of all ecosystem services that would have been provided by that pristine state over future years. Only once the land was back to its pristine state, i.e., the converted land is allowed to regenerate, would the full ecosystem services be felt again. Each year as more land regenerates, more ecosystem services are provided, hence the increase in values from Year 2 onwards. The conversion coefficient is therefore the total value of lost ecosystem services until the land could theoretically regenerate (this methodology assumes this takes 100 years) and discounted to reflect the higher value society places on lost services today.

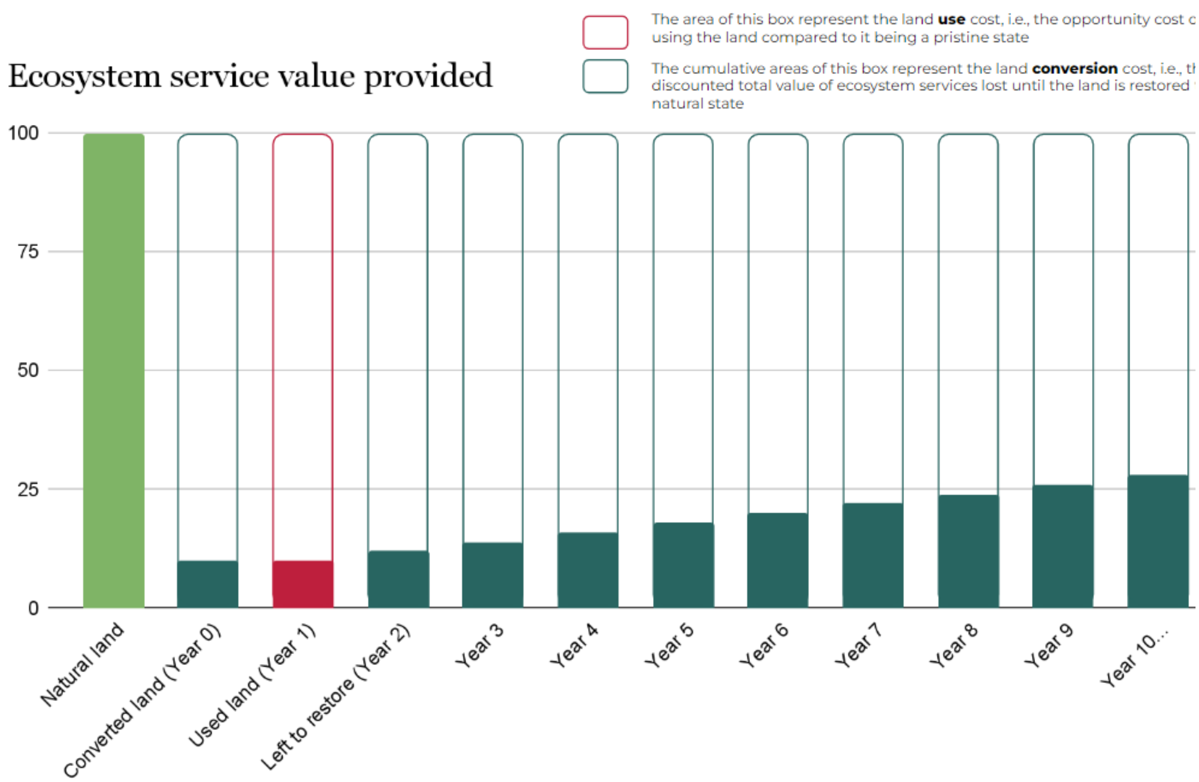

Figure 1: illustrative difference between land use and conversion

13. The Methodology covers the ecosystem service types contained within the Ecosystem Services Valuation Database[6] (ESVD), as presented in Table 1.

Service class	Specific ecosystem services	Geographical scope
Cultural	Opportunities for recreation and tourism	Local
	Aesthetic information	Local
	Inspiration for art, culture and design	Local
	Spiritual experience	Local
	Information for cognitive development	Local
	Existence, bequest values	Global
Provisioning	Medicinal resources	Local
	Food	Local
	Raw materials	Local
	Water	Local
	Ornamental resources	Local
Regulating	Climate regulation	Global
	Moderation of extreme events	Global
	Maintenance of genetic diversity	Global
	Maintenance of life cycles	Global
	Genetic resource	Global

[6] See Brander et al (2024).

	Erosion prevention	Local
	Waste treatment	Local
	Regulation of water flows	Local
	Maintenance of soil fertility	Local
	Pollination	Local
	Air quality regulation	Local
	Biological control	Local

Table 1: Ecosystem services valued in the Interim Land Use Methodology

14. The ESVD distinguishes between final ecosystem services that directly benefit people (including both use and non-use values) as well as intermediary or supporting ecosystem services (which support the provision of final ecosystem services). Only final ecosystem services are included in this methodology as the inclusion of intermediary or supporting services would lead to double counting[7]. Supporting services include those that are necessary for all other ecosystem services to function, such as habitat provision, but if included these values would be double counting the value of ecosystem services that are underpinned by the supporting services.

15. The extent to which people are affected by losses of ecosystem services will depend on the geographical scale at which these services operate. For example, harvesting of food and fiber from natural areas tends to benefit local populations, whilst climate regulation is a global benefit. This geographical scope (Table 1) defines the population impacted as a result of ecosystem loss.

16. The scope and boundaries of the Interim Land Use Methodology includes full value chain land use and conversion. 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 land use and conversion production may be based on models and not directly measured due to the challenges of measuring upstream and downstream data.

[7] See Haines-Young, R. and Potschin, M. (2017), Common International Classification of Ecosystem Services (CICES).

17. The Interim Land Use Methodology recognizes full responsibility of an entity for its upstream and downstream waste production. Land use and conversion is attributed to an entity through physical or economic relationships by portioning the inputs or outputs of land use and conversion and determining the portion that is linked to the entity. The inclusion of value chain land use and conversion 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.

18. This methodology follows an ecosystem approach[8] by valuing services provided by the ecosystem, rather than individual constituents of a specific ecosystem itself. This is generally accepted[9] as the most robust approach to the measurement of societal values relating to land use changes. However it is an evolving approach with several key considerations:

    a) The ecosystem services set out in Table 1 are a significant simplification of the many and varied benefits that society receives from the environment, so any valuation of this will itself be a simplification of reality.

    b) Methods for valuation of ecosystem services are evolving rapidly and the choice of method can have a significant impact on the resulting valuation. Even basic alignment of ecosystem service classifications across frameworks, concepts, and definitions is imperfect.[10]

    c) Even if alignment between frameworks, concepts, and definitions were perfect, the difficulties that ecologists face in linking changes in ecosystems with changes in the provision of services mean that ascribing precise values to marginal changes in ecosystems remains some way off in the future.

    d) The Methodology uses a 'counterfactual' of the ecosystem service value provided by the so-called 'pristine' biome of a region, i.e. the theoretical biome that would exist without human alteration or use of the land.

19. Based on the above, the Methodology covers the use value society gains from ecosystems (such as climate regulation, food, and fuel) and non-use values (such as cultural experiences and education). It does not aim to quantify the intrinsic 'value' of nature outside of the realm of human preferences.

[8] See Convention on Biological Diversity – Ecosystem Approach (2024).

[9] See The Ecosystem Approach, The Parliamentary Office of Science and Technology Postnote (2011).

[10] La Notte et al (2017).

2 Impact Pathway

2.1 Summary

20. The impact pathway is the series of consecutive, causal relationships, 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

21. Detailed components of the impact pathway are outlined in subsequent sections, leading to the valuation of an entity's land use and conversion in *Section 4: Outcomes, Impacts, Valuation.*

22. The impact pathway for the Methodology is as follows:

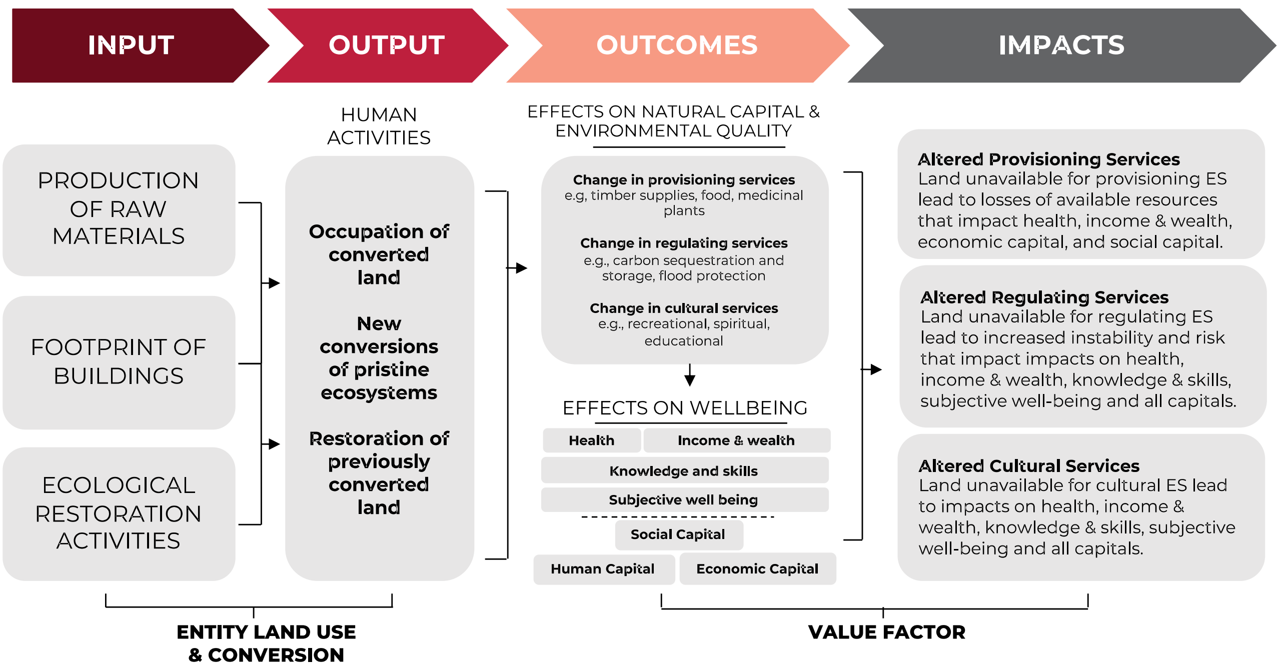

Figure 1: Land use and conversion impact pathway

2.2 Description and notes

23. The primary inputs for land use and conversion are production of raw materials and industrial footprint across the entity's own operations and value c. As these are the main drivers of land use and conversion, most corporate activities — from the goods that an entity procures to developments that entities enact — will generate impact on land.

24. The outputs of the entity are (1) the use of converted land, (2) new conversions of pristine ecosystems, or (3) in cases where restoration activities are undertaken, restoration or enhancements of previously converted land.

25. The occupation and conversion of land alters the physical environment and reduces (or in cases of restoration, increases) the amount of ecosystem services provided by the land. These ecosystem services include changes in provisioning services, such as food and fibers, changes in regulatory services, such as carbon sequestration and storage, and change in cultural services, such as recreation and education. The impact pathway and the value factors in the Global Value Factors Database cover the use of land, rather than restoration, as this is expected to be the principal impact created.

26. These changes to the physical environment drive numerous impacts that alter the condition of the natural environment and the well-being of people. These include economic impacts from reduced ecosystem productivity, health impacts from altered assimilation capacity of air and water, and cultural impacts from reduced recreational services (see Table 1 for a full list of ecosystem services included in the model).

27. The Interim Land Use Methodology is unique from some other Topic Methodologies in that the effect on humans (i.e., the impacts) are not individually valued. Rather, it takes the value of ecosystem services lost (i.e., the outcomes). Within these total value of ecosystem services lost, the impacts on humans have been valued, implicitly or explicitly, by the studies included in the ESVD repository. Using an econometric approach to value impacts would theoretically be possible, however the number of relevant variables is large, each with limited explanatory power to identify a systematic relationship[11].

28. 'Cultural impacts' refers specifically to the cultural value derived from ecosystem series, rather than land access or rights (although access and rights to land can be important for accessing and benefitting from ecosystem services).

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[11] Van der Ploeg (2010) come to the same conclusion with their analysis of the TEEB database, the predecessor to the ESVD database.

3 Impact Driver Measurements

29. Impact drivers consider inputs and outputs and reflect the data needs expected of a preparer to provide an impact account for land use and conversion. The section below outlines the specific data needed along with how preparers should consider data gaps and uncertainty.

3.1 Data requirements

30. The Interim Land Use Methodology requires the total hectares of land that an entity uses and has converted, organized by the raw material provided by the land (outlined below), the country in which the materials originate from, and whether the entity has converted this land itself or is occupying previously converted land.

Data input		Country	Country 2	Country 3
Land Use or Conversion in Own Operations				
Hectares of Land Used / Converted	Wheat	/	/	/
	Vegetables, fruits, nuts	/	/	/
	Cereals, grains	/	/	/
	Oil seeds	/	/	/
	Sugarcane, sugar beet	/	/	/
	Plant-based fibers	/	/	/
	Other crops (conventionally, organic or sustainably farmed)	/	/	/
	Bovine, sheep, goats, horses (conventionally, organic or sustainably farmed)	/	/	/
	Cashmere (conventionally,	/	/	/

	organic or sustainably farmed)			
	Forestry	/	/	/
	Paddy rice	/	/	/
	Paved (buildings)	/	/	/
Land Use or Conversion in Upstream Value Chain				
Hectares of Land Use / Converted	Wheat	/	/	/
	Vegetables, fruits, nuts	/	/	/
	Cereals, grains	/	/	/
	Oil seeds	/	/	/
	Sugarcane, sugar beet	/	/	/
	Plant-based fibers	/	/	/
	Other crops (conventionally, organic or sustainably farmed)	/	/	/
	Bovine, sheep, goats, horses (conventionally, organic or sustainably farmed)	/	/	/
	Cashmere (conventionally, organic or sustainably farmed)	/	/	/
	Forestry	/	/	/
	Paddy rice	/	/	/

	Paved (buildings)	/	/	/
Land Use or Conversion in Downstream Value Chain				
Hectares of Land Use / Converted	Wheat	/	/	/
	Vegetables, fruits, nuts	/	/	/
	Cereals, grains	/	/	/
	Oil seeds	/	/	/
	Sugarcane, sugar beet	/	/	/
	Plant-based fibers	/	/	/
	Other crops (conventionally, organic or sustainably farmed)	/	/	/
	Bovine, sheep, goats, horses (conventionally, organic or sustainably farmed)	/	/	/
	Cashmere (conventionally, organic or sustainably farmed)	/	/	/
	Forestry	/	/	/
	Paddy rice	/	/	/
	Paved (buildings)	/	/	/

Table 2: Land use data requirements

31. The most influential factor in determining the environmental outcomes associated with land use is the raw material that is produced from the land, along with the country in which the produce comes from. It is therefore important to understand where the raw materials come from, along with how much land would be used to produce that

quantity. As it is likely the hectares of land used along an entity's supply chain will not be known, and difficult to obtain, these can be estimated using yield to hectare conversion factors.

32. The data requirements of the Interim Land Use Methodology are aligned with and expand upon disclosure requirements established by relevant standard setters including European Sustainability Reporting Standards E4: Biodiversity and Ecosystems and the Global Reporting Initiative 304: Biodiversity 2016. Additional alignment may exist with other regional or topic specific reporting standards as well.

Metric	ESRS	GRI
Land Use and Conversion – own operations	Expands upon E4-5, paragraph 35 and 38, page 132	Expands upon Disclosure 304-1 (a) and Disclosure 304-2 (a)
Land Use and Conversion – value chain	Expands upon E4-5, paragraph 35, page 132	Expands upon Disclosure 304-1 (a)
Location of Land Use and Conversion	Independent from E4-5, paragraph 35, page 132	Independent from Disclosure 304-1 (a)

Table 2: Alignment with reporting standards[12]

3.2 Data sources, gaps, and uncertainty

33. Preparers should strive to measure land use in a manner that is complete, neutral, and free from error. This includes faithfully representing the land use from all parts of the value chain.

34. In practice, obtaining full value chain land use 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, land use impacts.

35. To determine land use, knowledge of an entity's own physical operational footprint, as well as that of their suppliers, is needed. Land use footprint of an entity's own operations should be available from company management information. Land use

[12]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.

footprint of immediate suppliers and upstream supply chain is likely harder to obtain; where this is unavailable, gaps in metric data can be filled using modelling techniques such as life-cycle assessment or environmentally extended input-output modelling. Both approaches have developed frameworks for determining land use but may differ in levels of data specificity or considerations depending on the context of application.

36. The types of raw materials produced from the land will need to be established, along with the source location of these materials. This may be known by the entity or obtained from suppliers. Where data is not available, production models or trade data (including environmentally extended input-output modelling) can be used to identify the most likely source locations.

37. The availability of actual (rather than modelled or estimated) metric data will vary according to the company's level of control over the producers and users of this information. This is likely to vary across a company's value chain as described below:

    a) **Own operations:** Land use footprint of buildings should be available from company management information.

    b) **Immediate suppliers:** Land use footprint of buildings may be available from suppliers. Where this is unavailable, gaps in metric data can be filled using modelling techniques such as EEIO.

    c) **Upstream / supplier data:** Footprint of buildings can be estimated using EEIO and LCA (or inferred from other suppliers). Land use footprints of raw materials can be estimated using production models, based on data on raw material demand from the company and its manufacturing suppliers. The source location of these materials may be known by the company. If this is not the case, suppliers may be able to provide the information or trade data can be used to identify the most likely sources.

    d) **Downstream / use phase:** Land use area is highly dependent on the product in question. Cars require car parks and garages. However, many products such as clothing or cosmetics have no direct land use requirements. Indirect land use (e.g. rubber production for tires) can be estimated using production models, based on assumptions on the quantity of raw material used which may be available from customer surveys or industry information. EEIO and LCA can also be used to estimate indirect land use where appropriate.

    e) **End of life / reuse impacts:** Land use area can be modelled using EEIO or LCA techniques. This may be further informed by customer surveys or industry information.

38. Preparers should prioritize approaches that:[13]

a) Directly measure land use and converted over those that estimate 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.

39. High quality data sources should consider:[14]

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?

40. Other resources may provide guidance for land use estimation including the GHG Protocol Land Sector and Removals Guidance[15] and the IPCC Good Practice Guidance for Land Use.[16]

41. Uncertainty will arise when quantifying land use. Preparers should report qualitative uncertainty and, when possible, quantitative uncertainty. These may include but are not limited to propagated measured uncertainty, pedigree matrices, sensitivity analyses, or probability distributions.

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[13]Language adapted to water consumption from the Greenhouse Gas Protocol. (2011). Corporate value chain (scope 3) accounting and reporting standard.

[14]Language adapted to water consumption from the Greenhouse Gas Protocol. (2011). Corporate value chain (scope 3) accounting and reporting standard.

[15] See Greenhouse Gas Protocol (2022)

[16] See IPCC (2019)

4 Outcomes, Impacts and Valuation

42. The impacts that result from land use and conversion affect the environmental quality dimension of well-being and the well-being resource of natural capital. These are linked to the well-being of people via the impacts of ecosystem services on effects on health, economic capital, and cultural value.

43. The impact pathway in this statement has been developed using value factors that collapse the impact measurement and valuation stages into a summary value. As discussed in Section 2.2, the Interim Land Use and Conversion Model utilizes the ESVD valuation of ecosystem services to determine the value of lost services (i.e., the value of outcomes in the Impact Pathway). Combining the hectares of land being used or converted (outputs) to the value factor (outcomes and impacts) determines the negative cost of land use and conversion. Value factors are country-specific and therefore are applied to country-specific quantity data on the land area attributed to the entity per country.

4.1 How to calculate impacts

44. To determine the monetary cost of land use (Land Use ValueTotal) and land conversion (Land Conversion ValueTotal) preparers should use the following equations:

Land Use

Land Use Value$_{\mathbf{Total}}$ = $\sum(Land\ Use\ Impact_{country})$ for all countries (Eq. 1)

Land Use Impact$_{country}$ = $LU\ Area_{country} * VF_{LU\ country}$ (Eq. 2)

Land Conversion

Land Conversion Value$_{\mathbf{Total}}$ = $\sum(Land\ Conversion\ Impact_{country})$ for all countries (Eq. 3)

Land Conversion Impact$_{country}$ = $LC\ Area_{country} * VF_{LC\ country}$ (Eq. 4)

45. The variables for the equations are as follows:

$VF_{LU\ country}$	The value factor for land use based on the country of land use. The value factor should be obtained for each country where land is used and can be obtained from the Global Value Factors Database.
$LU\ Area_{country}$	The area of land use (ha) organized by the country where that land is used. Land use is determined by an entity and described in Section 3.1.

$VF_{LC\ country}$	The value factor for land conversion based on the country of land use. The value factor should be obtained for each country where land has been converted and can be obtained from the Global Value Factors Database.
$LC\ Area_{country}$	The area of land converted (ha) organized by the country where that land has been converted. Land conversion is determined by an entity and described in Section 3.1.

46. The land use and land conversion impact calculations are described below.

a) Determining land use impacts:

- Land use impacts are determined by multiplying the land being used, in hectares, ($LU\ Area_{country}$) by the country value factor ($VF_{LU\ country}$) where that land is used as described in equation 2. Equation 2 should be calculated separately for each location to obtain each country specific impact. After applying equation 2 for each country, the total land use impact can be determined by summing all country impacts using equation 1.

b) Determining land conversion impacts:

- Land conversion impacts are determined by multiplying the land that has been converted, in hectares, ($LC\ Area_{country}$) by the country value factor ($VF_{LC\ country}$) where that land was converted as described in equation 2. Equation 2 should be calculated separately for each location to obtain each country specific impact. After applying equation 2 for each country, the total land conversion impact can be determined by summing all country impacts using equation 1.

47. Upstream value chain, downstream value chain, and own operations of waste production should always be considered separately to increase transparency, comparability, and decision-usefulness. Additional levels of detail may be useful such as an assessment of land use or conversion organized by land types, at regional scales, or within specific value chain categories.

48. The value factors in the Global Value Factors Database cover the use of land that is negatively altered from the pristine state, as this is expected to be the principal impact created. Because these land uses and conversions lead to negative impacts to stakeholders via lost ecosystem services, the land use and conversion impacts are negative.

4.2 Outcomes and impacts

49. The Methodology presented here is intended for use with global supply chains, offering a method to calculate the impact of land use and conversion via lost ecosystem services. The approach is described below with additional methodological details available in *Appendix B: Methodological Details*.

50. For both land use and land conversion, the value of land is determined through the ecosystem services framework. This is done by using the Ecosystem Services Valuation Database (ESVD),[17] a meta-analysis of 9,500 ecosystem service estimates across 6 continents. The studies in this analysis use numerous objective and subjective well-being indicators and methods to determine impacts across 23 individual ecosystem services that fall into four broad categories – provisioning services, regulating services, habitat services, and cultural services.[18]

51. Outcomes and Impacts are assessed by first determining the value of ecosystem services from a pristine biome in that location. Then the extent of ecosystem service loss that occurs as a result of the current land use or conversion is then determined.

    a) **Pristine ecosystem service value:** The pristine natural state of an ecosystem represents the maximum ecosystem service value that could be obtained from land. For each country, this is calculated by multiplying biome areas (in hectares) by the average ecosystem service value of each biome (in $ / hectares / year, based on the ESVD[19]). In addition, the value for each country is adjusted for income, population density and rural population (in a combined scaling factor). This scaling factor reflects the assumption that highly dense countries and/or countries with high rural populations value ecosystem services more than less dense and/or more urban countries. This assumption is applied based on higher scarcity and higher opportunity cost principles.

    b) **Extent of ecosystem service lost:** We then calculate the proportion of ecosystem services that would be lost based on the conversion to specific managed land types (listed in Table 2). Three variables that mediate ecosystem service value are used as proxies to estimate ecosystem service loss: relative biomass, species richness, and soil organic carbon (SOC). The proportion of each proxy in the

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[17] De Groot, R. et al. (2012). *Global estimates of the value of ecosystems and their services in monetary units*.

[18] For definitions of these categories, see the Glossary.

[19] ESVD Summary Statistics show the mean standardized values for each selected biome and ecosystem service in international dollars / hectare / year in 2020 price levels. A common outlier exclusion rule based on a standard boxplot graph is used to remove studies that skew the value excessively.

converted land use relative to the pristine land use is used to determine the extent of ecosystem service lost.

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 valuation approach utilizes the ESVD. Because the ESVD represents a meta-analysis of 9,500 ES estimates across 6 continents, there are many valuation approaches used in this analysis. Some of the more common approaches in the database include market prices, damage costs, contingent valuation, and choice modelling.

53. The impact of land use or conversion is the ecosystem service loss (%) of the pristine ecosystem service value ($/ha). The country impact is then calculated as the average across the relevant biome types, weighted by the proportion of the country area that consists of each biome. The output from this calculation represent **the current marginal value** of ecosystem services, or in other words, the value of impacts of an additional hectare of land being converted today.

54. Land conversion changes drive ecosystem service loss impacts well into the future. This topic methodology assumes it takes 100 years for full ecosystem service recovery. The Land Conversion Value Factor conversion represents the total value of lost ecosystem services over 100 years[20] discounted at a rate of 2% to reflect the net present value of lost ecosystem services.

55. For the Land Use Value Factor, using the current marginal value is inappropriate for land that was converted in the past, for which the entity is not responsible for. The Land Use value factors are therefore calculated by taking **the average of the marginal values**. The rationale for this is depicted in Box 2. Taking the average represents the increase in scarcity that is felt as more pristine land is lost. The rationale for this is detailed further in *Appendix B: Methodological Details*.

56. It is highly likely that if an entity does convert a hectare of land, they will then use that land the following year. In such cases, the decision to use land for an additional year shifts the potential regeneration period back by one year and imposes another year of undiscounted ecosystem service loss. An entity should therefore account for this by adding another year of the current marginal value of ecosystem services lost to the Conversion Value Factor.

[20] Based on Green Book guidance on the average time it takes for land to regenerate to its pristine state, see HM Treasury, The Green Book (2022).

Box 2: Average of marginal values

In order to calculate the average of marginal values a relationship between the extent of natural land area lost over time and the corresponding value loss associated with converting an additional hectare is assumed. Figure 1 illustrates a number of possible relationships. The graph demonstrates that, if the current marginal value (y) was applied to all areas of land use, the impact given by the area under line (i) would be a gross over-estimate. Three different curves are shown to illustrate the possible relationship: in curve A, costs increase linearly while, in B and C, the incremental costs increase slowly at first and then more rapidly as a greater total area is lost. Whilst one of these relationships may hold true, the actual relationship will differ across ecosystem services in different contexts.

Given this, a linear relationship (Curve A) is assumed in the calculations. This is a conservative approach and leads to higher estimates of potential impacts (since any other convex relationship would suggest impacts of past conversions are lower). In this instance, it is straightforward to calculate the average marginal cost, as it is half the current marginal cost.

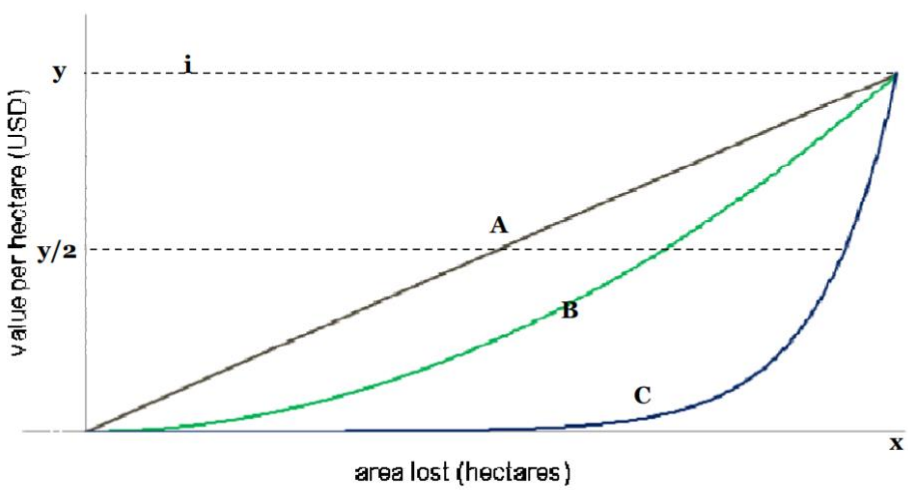


Figure 1: Ecosystem services have increasing marginal value as more natural areas are lost

5 Future Development

57. The impact pathway and valuation methods presented in the Land Use Methodology represent the current state of knowledge built upon decades of rigorous scientific work. But some limitations still exist including the ability of entities to have a complete visibility of land use across their value chain, as well as economic and ecological difficulties in estimating the true value of ecosystem services.

58. There are opportunities to further advance impact accounting by exploring new pathways that overcome limitations and reduce uncertainty. Some of these include:

    a) Development of studies and research methods that allow for more complete and accurate understanding of ecosystem service value. Valuing ecosystem services on a more granular, site-specific level would allow for more accurate quantification of impacts.

    b) Improvements in economic methods for estimating and linking the impacts of ecosystem service loss on welfare losses in society would create value factors for specific impact pathways within the Interim Land Use and Conversion Methodology, and allow for greater transparency on individual entity impacts.

    c) The development of standardized reporting frameworks specifically designed for land use across value chains would provide companies with clear guidelines and metrics to measure and report their land use impacts consistently, along with providing better visibility both up- and downstream.

    d) The integration of emerging technologies, such as remote sensing, satellite imagery, and geospatial data, could enable more accurate and efficient monitoring and assessment of land use and conversion. These technologies can provide real-time data on land cover changes, land conversion, and other relevant metrics.

    e) Improved traceability systems would help entities track the origin of their raw materials and products throughout the value chain. This would enable better identification of land use impacts associated with specific suppliers or regions, allowing for more targeted reporting and valuation of impacts.

    f) Integrating natural capital accounting approaches into corporate reporting, alongside improvements in economic valuation methods, would provide a more comprehensive understanding of the environmental and economic impacts associated with land use across value chains.

59. 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.

Appendix A: Glossary

Term	Definition	Source
Biomass	The total mass of organisms in a given area or volume.	National Geographic Society
Discount factor	A factor used to adjust future costs or benefits to their present value, taking into account the time value of money.	US Council of Economic Advisors
Ecosystem	A biological community of interacting organisms and their physical environment.	National Geographic Society
Environmentally extended input-output modelling	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.	N/A (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.	N/A (GM1)
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)
Life-cycle assessment	A comprehensive analysis of the environmental impacts of a product or process throughout its entire life cycle, from raw material extraction to disposal.	EPA
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)
Species	A group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding.	National Geographic Society
Soil organic carbon	The carbon component of organic compounds in soil, which includes plant and animal detritus, cells and tissues of soil organisms, and substances synthesized by soil organisms.	FAO

Appendix B: Methodological Details

B1. The Interim Land Use and Conversion Methodology incorporates the societal impacts associated with all land use and conversion that can be attributed to a company's operations and therefore may need to cover multiple geographies across expansive global supply chains. The valuation approach first establishes the value of a pristine biome and traces the share of land use for which the company is responsible. It then goes on to estimate the extent of service loss that occurs as a result of the change in use. An estimate of the societal impacts of these lost services is then determined in the final step.

Ecosystem service valuation module

B2. This module estimates the value of a theoretical 'pristine' biome before it has been converted to an anthropogenic use. The value of an ecosystem is driven by the different ways in which its services provide benefits to society. The total value of a hectare of a given ecosystem is the sum of the value derived from each of the ecosystem services it provides. These individual ecosystem service values are obtained from the ESVD Summary Statistics.

B3. ESVD is a repository of over 10,000 value records across 2000 studies,[21] which estimate the value of specific ecosystem services for different biomes across the globe. These values are summarized into summary statistics providing the mean standardized values from the studies in its repository across 15 biomes and 23 ecosystem services.

B4. Once the value of specific ecosystem services across biomes has been established, values are assigned to the six biomes that form the outputs of the model: tropical forests, temperate / boreal forest, grasslands, desert / arid grassland, inland wetlands and coastal wetlands. Some of the biomes included in the ESVD database are excluded based on their applicability to the model (e.g., marine, subterranean, and urban biome values are excluded, for example, as they are not 'land' values or reflect the value of land already interfered with by humans).

B5. Values are then adjusted per country based on three factors:

a) **Country income:** To reflect the differing purchasing power across countries, and therefore the differing ability-to-pay for ecosystem services, the values are baselined to 2023 US dollars and then adjusted based on the purchasing power per capita of countries.

[21] See Brander et al (2024).

b) **Population density and rural distribution:** To reflect the assumption that more densely populated countries and those with higher rural populations value ecosystem services higher (as they are scarcer, benefit more people, and / or rely more heavily on the outputs of the land), a scaling factor based on these identities are applied.

c) **Biome distribution:** The values of ecosystem services per biome are apportioned to countries based on the percentage of biome that is present in each country. This reflects the value of ecosystem services that would be produced if each country was in a 'pristine state.'

B6. The final values represent the ecosystem service benefits that would be felt were every country in a 'pristine' state, as if their natural lands had experienced no conversion to an anthropogenic land use. These values then establish the value of ecosystem services lost when these lands are changed, as outlined in the next module.

Extent of ecosystem service lost module

B7. The ecosystem loss module calculates the change in ecosystem services and therefore defines the environmental outcomes of the land use in each location. The change in ecosystem service loss, expressed as a percentage, varies significantly according to the type of land use change. Where the extent of services lost can be determined directly, when exact location is known and data is available for specific estimates of ecosystem service provision, the actual service loss can, in principle, be calculated.

B8. However, for entities with large global supply chains this is likely not possible. In such cases, as with this model, the changes in relative biomass, species, and SOC expected with changes in land use can be estimated. There is ecological support for a relationship between these variables and ecosystems functioning[22], however it is recognized this is a crude approximation of the complexity of different ecological systems globally.

B9. Table 2 identifies the proxy variables used for each ecosystem service. The different combinations of biomass, species and SOC represent the variables that form a significant basis of the specific ecosystem services that would be lost were the land changed. In this case the assumption that the land is changed through agricultural production or other industrial processes, which is the case for the majority of the conventionally farmed and industrial outputs that this model provides. This means that some ecosystem services experience full loss, e.g., the ability to collect raw materials from a tropical rainforest will be fully lost if that land is turned into a wheat field. However, some services will be impacted by specific variable loss, e.g., climate

[22] Hooper et al (2005).

regulation will be primarily impacted by loss of biomass and SOC through carbon sequestration, but loss of species will have less of an impact on this service.

Service class	Specific ecosystem service	Proxy loss combinations
Cultural	Opportunities for recreation and tourism	Biomass & Species & SOC
	Aesthetic information	Full loss
	Inspiration for art, culture and design	Full loss
	Spiritual experience	Full loss
	Information for cognitive development	Biomass & Species & SOC
Provisioning	Medicinal resources	Full loss
	Food	Full loss
	Raw materials	Full loss
	Water	Full loss
	Ornamental resources	Full loss
Regulating	Climate regulation	Biomass & SOC
	Moderation of extreme events	Biomass & SOC
	Maintenance of genetic diversity	Biomass & Species & SOC
	Maintenance of life cycles	Biomass & Species & SOC
	Genetic resource	Biomass & Species & SOC
	Erosion prevention	Biomass & SOC
	Waste treatment	Biomass & SOC
	Regulation of water flows	Biomass & SOC
	Maintenance of soil fertility	Biomass & Species & SOC

	Pollination	Biomass & Species & SOC
	Air quality regulation	Biomass & SOC
	Biological control	Biomass & Species & SOC
Cultural	Existence, bequest values	Full loss

Table 2: Proxies for the relative change in ecosystem services

B10. The percentage loss of biomass and species are calculated in the same way: the estimated biomass and species richness for a changed land type (e.g. biomass density and species number in a hectare of wheat field), divided by the estimated incidence of biomass and species in a pristine biome (e.g. biomass density and species numbers in a hectare of tropical rainforest). The resulting value is the percentage of either biomass or species lost in the land conversion.

B11. SOC change is estimated through the IPCC's Land Use, Land-Use Change and Forestry guidance on SOC change factors[23]. There is, however, adjustment given if the land is assumed to employ sustainable land management practices. These are estimated through applying different factor weightings to the variables that form SOC estimates, as outlined in (b) below.

a) Percentage of SOC remaining in a managed land type is estimated using the IPCC's[24] calculations for relative carbon stock change factors. The proportion of carbon in managed land can be estimated through this equation:

$$SOC = SOC_{REF} \times F_{LU} \times F_{MG} \times F_I$$

Where:

SOC = Soil Organic Carbon stock for inventory year, metric tons C/ha

SOC_{REF} = the reference carbon stock, metric tons C/ha

F_{LU} = stock change factor for land use type

F_{MG} = stock change factor from management regime

F_I = stock change factor for input of organic matter

[23] See IPCC (2019).

[24] See IPCC (2019).

b) This equation shows that SOC stock is dependent on the type of management regime the landowner employs (alternatively, how much tillage is applied to the soil) and how much input of organic matter is utilized (alternatively, how much manure is used in farming processes). We hence differentiate between sustainable and conventional land practices by weighting these variables as shown in Table 3.

Land type	Management (tillage) factor	Input (manure) factor
Crop – conventional cultivation	Full tillage	Low input
Crop – organic cultivation	Reduced tillage	Medium input
Crop – sustainable cultivation	No tillage	High input

Table 3: Example of different factor weightings for sustainable and organic land management

B12. The extent of ecosystem service loss is therefore calculated as the percentage of biomass, species richness and remaining SOC after conversion. Where the proxy loss combinations involve more than one of those variables, a simple average is taken. Where the loss combination is full loss, it is assumed 100% of that ecosystem service value is lost.

Total lost ecosystem service value module

B13. The extent of ecosystem service loss is given as a percentage per ecosystem service, per country. These are multiplied by the value of a pristine ecosystem services, calculated in the Valuation Module. This obtains the value of ecosystem loss when a hectare of land in a given country is converted into an anthropogenic land use.

B14. These estimates calculated above represent the current marginal value of ecosystem services by country, which is the equivalent of the value lost if an additional hectare of land was converted today. This value is manipulated in two different ways in order to obtain the Use and Conversion value factors:

a) **Land use:** It would be inappropriate to apply this current marginal value to land that was converted in the past. This is because the impacts associated with additional losses in ecosystem services increase as more natural areas are converted through time. There are two factors that contribute to this: increasing scarcity value and increasing marginal damage costs associated with cumulative environmental degradation. Rather than applying the current marginal value, the appropriate measure for land converted in the past is therefore the *average* of the marginal value, as shown in Box 2.

b) **Land conversion:** To calculate the conversion value factors, the *current* marginal value of ecosystem services is discounted at a rate of 2% over a 100-year time horizon. This represents the net present value (NPV) of lost ecosystem services were a hectare of land converted today and, theoretically, then left to regenerate in the following years. This value factor therefore represents the value of lost ecosystem services felt every year until that area is restored.

B15. The full value factors for Use and Conversion are shown in the GVFD. As the conversion factors represent the total value of ecosystem services lost until the land is able to regenerate, they are much greater than the Use factors, which only represent the value of lost ecosystem services in a given year.

B16. It is highly likely that if an entity does convert a hectare of land, they will then use that land the following year. In such cases, the decision to use land for an additional year shifts the potential regeneration period back by one year and imposes another year of undiscounted ecosystem service loss. An entity should therefore account for this by adding another year of the current marginal value of ecosystem services lost to the Conversion Value Factor.

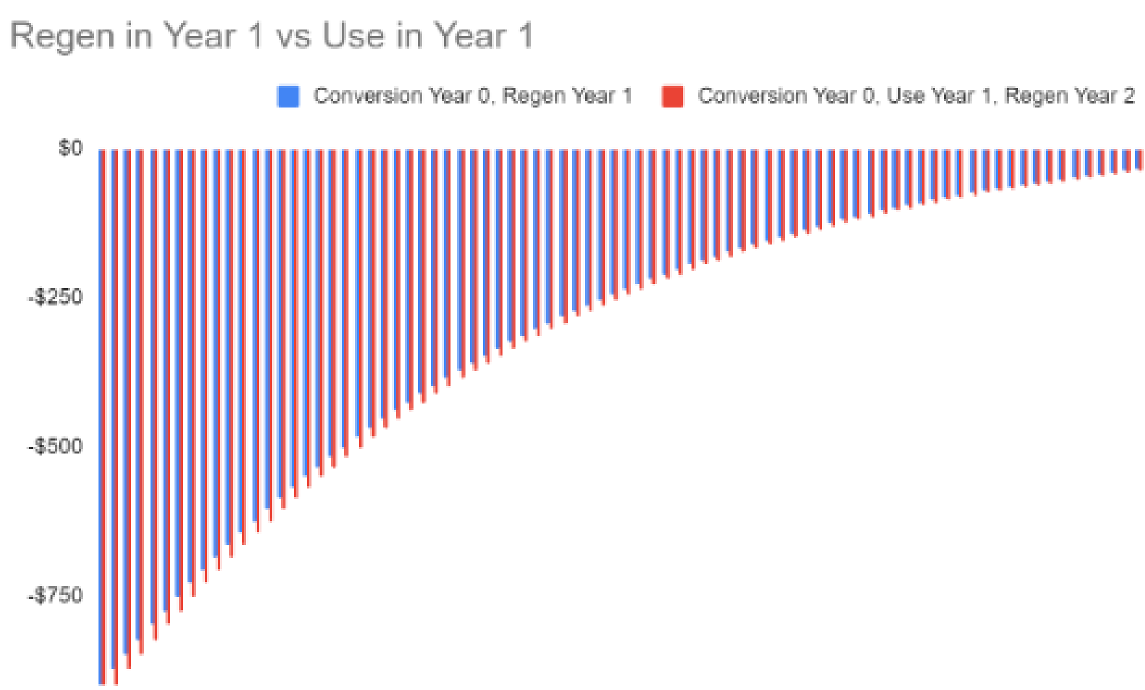
Box 3: Combining land use and land conversion coefficients

It is possible to assume that an entity using both the land use and land conversion value factors would be double counting their impact. For example, if an entity were to convert land, valuing the impact with the conversion value factor, and then value their use of the land the next year, would this be taking into account impacts that were accounted for the year before?

However, as Figure 3 shows, the decision to use the land for an additional year shifts the potential regeneration period back by one year and imposes another year of undiscounted ecosystem service loss.

The difference in total ecosystem service loss between the first and second scenario is one year's undiscounted lost ecosystem services, i.e., the land use value factor.

This is not included in the land conversion value factor so is not double counting.



Appendix C: Value Accountability Framework – Value Factors

This Appendix presents the Interim Land Use 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 Land Use and Conversion 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: The impact in dollars per hectare of land used for raw materials, in specific countries, along with the impact in dollars per hectare of land converted for raw materials, in specific countries.</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.</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 all land use and land conversion within the entities full value chain.

2. The value factor captures many impacts quantified by leading models while future work will continue to explore the valuation of additional 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 MONETARY VALUE</th></tr>
<tr><td>Approach and specificity</td><td>5. Change in well-being is estimated through the loss of ecosystem service values, with the percentage lost from a land use change proxied for</td><td>9. The value of a pristine hectare of land is gathered through the ESVD database valuations.

10. These valuations are then scaled per country based on their</td></tr>
</table>

	based on species, biomass and soil organic carbon. 6. Percentage losses are calculated for each factor of this change, e.g. the percentage loss of species that occurs when a hectare of tropical forest is converted to wheat. 7. Proxy combinations of those three factors are applied to the ecosystem services provided. These different combinations reflect which of species, biomass and soil organic carbon each ecosystem service is reliant on for its full functioning. 8. These percentage combinations reflect the loss, or change, of ecosystem services when land is converted or used.	population density, rural population and GNI PPP per capita. 11. The percentage losses are applied to the value of a pristine land to get the monetary value of what is lost when land is converted or used.
Data inputs	12. Country-specific data is taken from the World Bank and FAO. Biomass, species, and soil organic carbon data is taken from literature. 13. For further data sets see Appendix B: Methodological Details and Appendix D: Data Sources in the Interim Land Use and Conversion Methodology.	
VIEWS OF AFFECTED STAKEHOLDERS		
Representation of stakeholders	14. As an interim methodology, these value factors have yet to undergo the due process of the official methodology, which includes additional stakeholder engagement and public comment.	
ETHICAL DECISIONS IN ESTIMATING SOCIETAL IMPACT		
Equity weightings and income adjustments	15. The Land use model applies a scaling factor adjusted for country GNI PPP per capita, which reflects the differing abilities to value (or pay to protect) a pristine hectare of land's ecosystem services. Without this, poorer countries could see the value of a hectare of land being higher than the average	

	income of that country, which does not accurately reflect how society in that country would value a pristine ecosystem. 16. Ecosystem service values that provide global benefits are valued based on a global average income, as the benefits accrue to stakeholders around the world. This includes carbon sequestration benefits which have impacts across multiple generations.
Accounting for future impacts	17. Future impacts are modelled in the conversion value factors. These are discounted at a rate of 2% over 100 years.
Other ethical considerations	18. N/A
SENSITIVITY	
Sensitivity to key variables	19. Sensitivity analysis was carried out for 3 land use types (wheat, vegetables, and paved), for 3 countries (United States, China and Nigeria). For full results see Table 4.

Table 4: Sensitivity analysis

Land Use		**United States**			**China**			**Nigeria**		
Variable	Flex	*Wheat*	*Vegetables*	*Paved*	*Wheat*	*Vegetables*	*Paved*	*Wheat*	*Vegetables*	*Paved*
Average ecosystem service value	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Pristine species richness	10%	1%	0%	0%	0%	0%	0%	0%	0%	0%
Converted land species richness	10%	-1%	0%	0%	0%	0%	0%	0%	0%	0%
Rural population	10%	7%	8%	8%	6%	6%	6%	3%	4%	4%
Scaling factor (changed bounds)	15%-85% (from 25%-75%)	-1%	0%	-1%	10%	10%	10%	8%	8%	8%
Land Conversion										
Time horizon for conversion	75 years (from 100)	-15%	-15%	-15%	-15%	-15%	-15%	-15%	-15%	-15%
Discount factor	3% (from 2%)	-19%	-19%	-19%	-19%	-19%	-19%	-19%	-19%	-19%

Appendix D: Data Sources in the Interim Land Use Methodology

Data	Source[25]	Year
Above ground biomass	FAO	2015
Ecosystem service valuations	ESVD Database	2023
Biome species numbers	Kier et al. (2005)	2005
Marsh/coastal species numbers	Więski et al. (2008)	2008
Grassland/pasture species	Tracy and Sanderson (2000)	2000
Grassland/pasture species	Goslee and Sanderson (2005)	2005
Grassland/pasture species	Adler et al. (2004)	2004
Cropland species	Mehmeti et al. (2009)	2009
Cropland species	Lindstrom et al. (2008)	2008
Grassland biomass	Mbaabu et al (2020)	2024
Mangrove biomass	IPCC Wetlands	2013
Marsh biomass	Więski et al. (2008)	2009
Pasture biomass	IPCC Grasslands	2006
Crop biomass	IPCC Cropland	2006
Forest biomass	IPCC Forest Land	2006
Soil organic carbon	IPCC Cropland	2006
Koppen-Geiger	GloH20	2023
Land use biomes	WWF	2012

[25] Sources are hyperlinked for your reference.

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INTERIM METHODOLOGY

Waste

Environmental Topic Methodology

The International Foundation for Valuing Impacts, Inc. (IFVI) is a section 501(c)(3) public charity dedicated to building and scaling the practice of impact accounting to promote decision-making based on risk, return, and impact.

Table of Contents

Executive Summary

- The Interim Waste Topic Methodology can be used by preparers of impact accounts to measure and value the impact of waste on people and the natural environment. The Interim Waste 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 waste in an entity's own operations as well as upstream and downstream in the value chain, considered separately;

    - organize waste data by type, hazardous or non-hazardous, the method of disposal, either landfill or incineration, at the geographical location that data is available;

    - utilize the impact pathway and value factors developed in this methodology to convert waste 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 Waste 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 waste production included in the methodology are reduced human health and well-being, disamenity, agricultural losses, and related impacts produced through greenhouse gas emissions and air pollution.

- **Section 3** establishes the data required from the entity to implement the Methodology. This includes waste produced in metric tons by location, organized by hazardous and non-hazardous, and whether waste is incinerated, sent to landfill, or unspecified.

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

- **Section 4** outlines the approach of the Methodology for measuring and valuing the impacts, focusing on four main drivers of impacts: leachate, disamenity, greenhouse gas impacts, and air pollution impacts.

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

- 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 Waste (henceforth, the Interim Waste 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 Waste 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 Waste Methodology can be used to inform internal decision-making, investment decisions, and understand the significance of waste 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 Waste Methodology can apply via this document and the Global Value Factors Database. Supporting resources include the Interim Waste Methodology Model and the Interim Waste 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 Waste 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. Over 2 billion metric tons of solid waste are generated globally every year, with at least 33 percent (as a conservative estimate) not disposed of in an environmentally safe

manner.[2] By 2050, it is expected this will increase drastically to 3.4 billion tons disposed of globally, outpacing population growth.[3]

8. Corporate activities in all sectors result in some level of solid waste generation across their value chains. The disposal of this waste can lead to a range of environmental outcomes that adversely affect human wellbeing, thereby carrying a societal cost. These impacts include those related to air pollution, disamenity, greenhouse gases, and leachate.

9. Each of these changes to the environment affects society by increasing human morbidity and mortality, negatively impacting agricultural output, reducing enjoyment of the environment, and contributing to climate change, which in turn increases incidence of extreme weather events.

10. The Interim Waste Methodology takes a societal perspective and not of a discrete affected stakeholder group by considering the impacts of all of society. By measuring and valuing the impacts on society, waste impact accounts can provide guidance to entities to manage and mitigate risks related to the impacts they have on stakeholders.

1.3 Scope and assumptions

11. For the purposes of the Interim Waste Methodology, only solid waste is included. Fluid waste is considered in the Water Pollution Methodology and gaseous waste is considered in the Air Pollution Methodology.

12. Most material impacts associated with solid waste are covered in this paper, but two classes of impact draw from other methodologies.

    a) For GHG and air pollution outcomes, waste disposal is an intermediate step (e.g., waste disposal then generates these outcomes).

    b) The approaches to quantifying these outcomes as they relate to waste disposal are hence defined in this Methodology but valued according to their respective Methodologies (*Greenhouse Gas Methodology* and *Air Pollution Methodology).*

13. The Interim Waste Methodology is concerned with the direct impacts of waste disposal, rather than related topics like inefficiencies in product design.

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[2] See The World Bank (2018): What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050.

[3] See The World Bank (2018): What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 in the Foreword.

14. The Interim Waste Methodology focuses on impacts associated with treating solid waste through incineration and landfill, including unmanaged dumpsites (sites where solid waste is left but which are not managed in ways that reduce their environmental impact). For most entities, these two methods will capture the vast majority of the associated environmental outcomes of waste disposal.

15. Waste impacts are local, thereby requiring the geographic location of waste for proper valuation. Value factors for the interim methodology are presented at the country level, while the same models can be utilized to produce more geographically precise value factors as well.

16. The impacts of recycling are not covered in the Interim Waste Methodology. The impact of a company recycling materials or using recycled materials as inputs will likely indirectly affect other waste flows captured in the methodology, but the resources used in the processing of recycling are not currently included.

17. The scope and boundaries of the Interim Methodology includes full value chain waste production. 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 waste production may be based on models and not directly measured due to the challenges of measuring upstream and downstream waste productions.

18. The Interim Waste Methodology recognizes full responsibility of an entity for its upstream and downstream waste production. Waste production is attributed to an entity through physical or economic relationships by portioning the inputs or outputs of waste production and determining the portion that is linked to the entity. The inclusion of value chain waste production 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.

19. The impacts of specialist waste processing are highly dependent on the impact materiality of such waste disposal to the business in question. For most value chains, specialist processing is not relevant, and given the potential range of processes and contexts the methodology does not attempt to present a generalized approach.

20. This methodology does not cover the impacts caused by littering, ocean waste or persistent plastics. Whilst impacts of these could include disamenity, ecosystem degradation and ecotoxicity, more work is required to understand the causal links in these impact pathways.

1.4 Key concepts and definitions

21. For the purposes of applying the Interim Waste Methodology, the following terms are defined as:

    a) **Hazardous waste:** Waste that is defined as particularly dangerous or damaging to the environment. Entities may wish to utilize their relevant regulator's official listings as to what types of waste are included under this definition.

    b) **Non-hazardous waste:** This covers all types of waste not classified as hazardous. In other contexts, it may cover all other waste not otherwise classified.

    c) **Incineration:** The combustion of solid waste. This produces various flue gases, residual fly ash and disamenity from the aesthetic qualities of incinerators. The heat produced by incineration may be recovered to produce electricity, known as energy recovery.

    d) **Landfill:** The disposal of solid waste in specially designated areas. Waste, excluding inert waste, decomposes in landfill sites, producing GHGs, leachate and disamenity effects. This methodology uses the term to cover everything from unmanaged dumpsites, where GHGs and leachate can escape into the environment; to impermeable lined, sanitary landfills, where methane is collected and, in some cases, combusted for to produce electricity, also known as energy recovery.

2 Impact Pathway

2.1 Summary

22. 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.

23. Detailed components of the impact pathway are outlined in subsequent sections, leading to the valuation of an entity's waste in *Section 4: Outcomes, Impacts, Valuation.*

24. The impact pathway for waste is as follows:

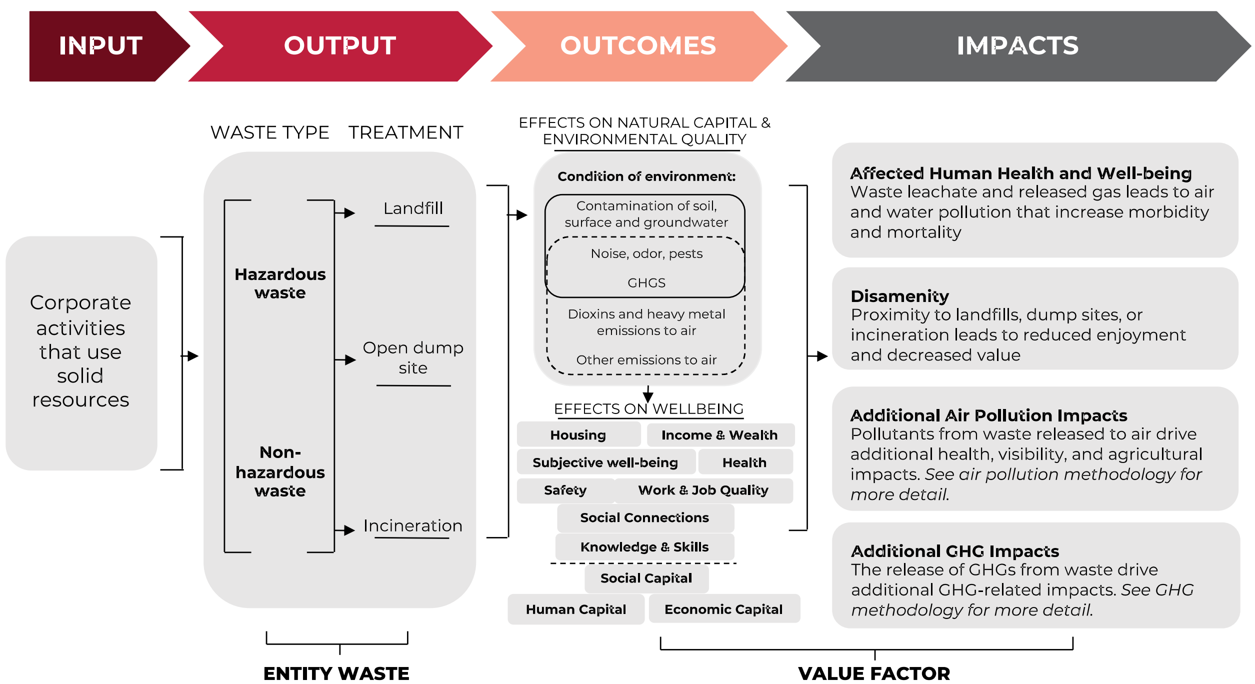

Figure 1: Waste impact pathway

2.2 Description and notes

25. The primary input for the waste impact pathway are corporate activities that generate solid waste output. This could include general municipal waste, biodegradable waste, sanitary waste, and / or clinical waste.

26. The output from the entity can then be categorized as hazardous or non-hazardous waste. This can then be further refined by the treatment with which the two types of waste receive (or, in other words, where the waste is sent to); landfill, open dump site,

or incinerator. These outputs would be expressed in units which can be measured at the corporate level.

27. The disposal and accumulation of waste has consequent effects that alter environmental quality and natural capital:

   a) **Air pollution:** As a by-product of waste incineration, where pollutants released reduce air quality and can cause health impacts, reduce visibility, and affect agriculture. The pollutants accounted for in this Methodology include particulate matter (PM2.5 and PM10), nitrogen oxides (NOx), sulfurous oxides (SOx), and heavy metals and dioxins.

   b) **Disamenity:** A wide range of impacts on local environmental quality, for example in terms of visual intrusion, odor, noise and pests.[4]

   c) **Greenhouse gases** (GHGs): Where waste disposal from both landfill and incineration release GHGs that contribute to climate change. The majority of GHGs from incinerators are in the form of carbon dioxide (CO_2) whilst those from landfill sites are methane (CH_4).

   d) **Leachate:** Where the release of liquid from solid waste disposed of in landfill sites, principally through the infiltration of rainwater, breaks waste down and the liquid produced contaminates the soil and local ground and surface water.

28. The extent of these impacts depends on how the waste is treated and disposed of – in particular, whether it is disposed of in a landfill site or an incinerator, as well as the specific characteristics of that waste disposal facility. For example, the contamination of soil, surface and ground water from incinerated waste is negligible and as such only landfill waste is accounted for in this specific impact pathway). The impact is also dependent on the type and composition of the waste (for example, whether it is hazardous or not, and its organic carbon content).

29. The consequential changes to the physical environment drive impacts that reduce the well-being of people. The categories of well-being affected include health, housing, income and wealth, subjective well-being, safety, work and job quality, social connections, knowledge and skills, economic capital, human capital, and social capital Specifically, the impacts include reduced human health and reduced enjoyment of the natural environment, as well as reduced agricultural output and ecosystem services due to contamination of soil and groundwater can impact agricultural output, and impacts on climate change through release of GHGs emissions.

[4] Ham et al (2013).

3 Impact Driver Measurements

30. Impact drivers consider inputs and outputs and reflect the data needs expected of a preparer to provide an impact account for solid waste.

31. Data requirements for the Interim Waste Methodology are aligned with and expand upon waste related sustainability reporting standards, which primarily captures the waste of non-hazardous and hazardous waste produced.

3.1 Data Requirements

32. The Interim Waste Methodology requires the total metric tons of waste generated by an entity. This should be separated into waste composition, specifically metric tons of hazardous and non-hazardous waste, and the waste disposal method, where known, as shown in Table 1.

33. If known, providing the waste treatments — either landfill or incineration — offers greater accuracy in choosing the value factors to apply to the waste generated. If waste disposal method is not known, an 'Unspecified treatment' value factor can be used.

Data input		Country 1	Country 2	Country 3
Waste Production in Own Operations				
Hazardous waste (metric tons), by location of disposal	Landfill			
	Incineration			
	Unspecified			
Non-hazardous waste (metric tons), by location of disposal	Landfill			
	Incineration			
	Unspecified			
Waste Production in Upstream Value Chain				
Hazardous waste (metric tons), by location of disposal	Landfill			
	Incineration			
	Unspecified			

Non-hazardous waste (metric tons), by location of disposal	Landfill			
	Incineration			
	Unspecified			
Waste Production in Downstream Value Chain				
Hazardous waste (metric tons), by location of disposal	Landfill			
	Unspecified			
	Incineration			
Non-hazardous waste (metric tons), by location of disposal	Landfill			
	Unspecified			
	Incineration			

Table 1: Waste data requirements

34. Further data on specific waste characteristics, such as fossil carbon percentage, or composition, such as principal materials, can be added into the Interim Waste Methodology Model for even greater precision.

35. Different types of waste, particularly hazardous and non-hazardous waste, will have different environmental outcomes in certain circumstances, and so they are often recorded separately. This distinction is particularly relevant to the impact on GHGs and leachate from landfill, as well as GHGs and air pollution from incineration. Despite inconsistencies in the definition of the two categories between countries, the approaches that we have developed or adapted from the literature in each of these areas take this distinction into account.

36. The most influential factor in determining the environmental outcomes associated with the disposal of solid waste is the mode of treatment. It is therefore important to understand how much waste is disposed of through landfill or incineration. If mode of treatment is not known, an ‘unspecified’ value factor is provided which gives whichever is larger of the landfill and incineration value factors per country. IFVI recognizes that this will only provide a picture of the average impacts in a given country.

37. The data requirements of the Interim Waste Methodology are aligned with and expand upon disclosure requirements established by relevant standard setters including European Sustainability Reporting Standards E5: Resource Use and Circular Economy

and the Global Reporting Initiative 306: Effluents and Waste 2016. Additional alignment may exist with other regional or topic specific reporting standards as well.

Metric	ESRS	GRI
Hazardous and Non-Hazardous Waste Production – own operations	Fully aligned with E5-5, paragraph 37 (c), page 150	Fully aligned with Disclosure 306-3 (a) and 306-5 (a)
Hazardous and Non-Hazardous Waste Production – value chain	Expands upon E5-5, paragraph 37 (c), page 150	Expands upon Disclosure 306-3 (a) and 306-5 (b)
Location of waste production	Expands upon E5-5, paragraph 37 (c), page 150	Expands upon Disclosure 306-5 (b)
Method of disposal	Expands upon E5-5, paragraph 38 (b), page 150	Expands upon Disclosure 306-3 (a)

Table 2: Alignment with reporting standards[5]

3.2 Data sources, gaps, and uncertainty

38. Preparers should strive to measure waste impacts in a manner that is complete, neutral, and free from error. This includes faithfully representing waste creation from all parts of the value chain.

39. In practice, obtaining full value chain waste 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, waste impacts.

40. To determine the impacts of waste, total metric tons of waste produced, and the disposal methods used, are both needed. These can be estimated directly, using data reported by the entity, or indirectly through techniques such as life-cycle assessment or environmentally extended input-output modelling. Where a direct approach is taken, waste data should be apportioned to landfill and incineration using actual data where available. Otherwise, general trends at a country or sub-national level can be used.

41. The availability of actual (rather than modelled or estimated) metric data will vary according to the company's level of control over the producers and users of this information. This is likely to vary across a company's value chain as described below:

[5]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.

a) **Own operations:** Waste tonnage, broken down by waste type and composition, should be available from company management information. The other estimation techniques detailed for the supply chain can also be used if direct data are unavailable.

b) **Immediate suppliers:** Waste tonnage, broken down by waste type and composition, may be available from some suppliers. Where this is unavailable, gaps in metric data can be filled using modelling techniques such as EEIO.

c) **Upstream / supply chain:** Reliable metric data on waste tonnage, type and composition are unlikely to be available from indirect suppliers. Metric data can be modelled using EEIO techniques, which may be further informed from industry information.

d) **Downstream / use phase:** Reliable metric data on waste tonnage, type and composition are unlikely to be available from users. Metric data can be modelled using EEIO techniques, which may be further informed from customer surveys or industry information.

e) **End of life / re-use impacts:** Some metric data can be derived using physical production characteristics, such as the masses of constituent materials. Other metric data can be modelled using EEIO techniques, which may be further informed from customer surveys or industry information.

42. Preparers should prioritize approaches that:[6]

a) Directly measure waste produced over those that estimate waste production 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.

43. High quality data sources should consider:[7]

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?

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[6]Language adapted to water consumption from the Greenhouse Gas Protocol. (2011). Corporate value chain (scope 3) accounting and reporting standard.

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

44. Various estimation techniques can be used to determine waste production. While a variety of techniques exist, those recommended for waste analysis include life cycle analysis (LCA) and environmentally extended input-output (EEIO) tables. Both approaches have developed frameworks for determining waste production but may differ in levels of data specificity or considerations depending on the context of application.

45. Uncertainty will arise when quantifying waste production. Preparers should report qualitative uncertainty and, when possible, quantitative uncertainty. These may include but are not limited to propagated measured uncertainty, pedigree matrices, 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.[8]

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

4 Outcomes, Impacts, and Valuation

46. The impacts that result from the waste production affect the environmental quality dimension of well-being and the well-being resource of natural capital. These are linked to the well-being of people through their effects on health, housing, income and wealth, subjective well-being, safety, work and job quality, social connections, knowledge and skills, economic capital, human capital, and social capital.

47. The impact pathway in this statement has been developed using a value factor that collapses the impact measurement and valuation stages into a summary value that is location-specific for each category of impact. The value factors can then be multiplied directly by entity-specific waste production consumption 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

48. To determine the monetary cost of waste production (Waste Value$_{Total}$), preparers should use the following equations:

$$\textbf{Waste Value}_{\textbf{Total}} = \sum(AP\ Impact_{ti} + DIS\ Impact_{ti} + GHG\ Impact_{ti} + LEA\ Impact_{ti}) \quad \text{(Eq. 1)}$$

for all types and treatments of waste in all countries

$$AP\ Impact_{ti} = Waste_{ti} * VF_{ti\ AP} \text{ for each country} \quad \text{(Eq. 2)}$$

$$DIS\ Impact_{ti} = Waste_{ti} * VF_{ti\ DIS} \text{ for each country} \quad \text{(Eq. 3)}$$

$$GHG\ Impact_{ti} = Waste_{ti} * VF_{ti\ GHG} \text{ for each country} \quad \text{(Eq. 4)}$$

$$LEA\ Impact_{ti} = Waste_{ti} * VF_{ti\ LEA} \text{ for each country} \quad \text{(Eq. 5)}$$

49. The variables for the equations are as follows:

$VF_{ti\ AP}$	The value factor for waste air pollution for each type of waste (hazardous or non-hazardous) and treatment type (landfill, incineration or unspecified). These values are distinct for each country where disposal occurs. The value factor should be obtained for each country where disposal occurs and can be obtained from the Global Value Factors Database.
$VF_{ti\ DIS}$	The value factor for waste disamenity for each type of waste (hazardous or non-hazardous) and treatment type (landfill, incineration or unspecified). These values are distinct for each

	country where disposal occurs. The value factor should be obtained for each country where disposal occurs and can be obtained from the Global Value Factors Database.
$VF_{ti\ GHG}$	The value factor for waste GHGs for each type of waste (hazardous or non-hazardous) and treatment type (landfill, incineration or unspecified). These values are distinct for each country where disposal occurs. The value factor should be obtained for each country where disposal occurs and can be obtained from the Global Value Factors Database.
$VF_{ti\ LEA}$	The value factor for waste leachate for each type of waste (hazardous or non-hazardous) and treatment type (landfill, incineration or unspecified). These values are distinct for each country where disposal occurs. The value factor should be obtained for each country where disposal occurs and can be obtained from the Global Value Factors Database.
$Waste_{ti}$	The kilograms of waste disposed of for each type of waste (hazardous or non-hazardous) and treatment type (landfill, incineration or unspecified)
t	type of waste (hazardous or non-hazardous)
i	treatment type (landfill, incineration or unspecified)

50. The waste production impact calculation is described below.

    a) Equations 2 - 5 calculate the monetary value of impacts for each of the four components of the waste impact pathway, including air pollution, disamenity, greenhouse gas emissions, and leachate, based on the location, waste type, and treatment type specific value factors presented as part of the Global Value Factors Database. Where waste treatment is unknown, the methodology applies an “unspecified” treatment value factor by taking a worst-case value factor, i.e. whichever is higher of the landfill or incineration value factor in a given country. The value factor for each can be multiplied by the waste produced. These equations should be calculated separately for each of the categories provided.

    b) After determining each impact, the total waste impact can be determined by summing the four impacts for each location, waste type, and treatment type.

51. Upstream value chain, downstream value chain, and own operations of waste production 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

52. For each impact, the approaches used to link water consumption to outcomes and impacts are described below. Additional methodological details are in Appendix B.

a) **Air pollution, *from incineration*:** the impacts for air pollution are calculated through two means.

- Country incineration emissions factors are used to estimate the kilograms of dioxin and heavy metals released per metric ton of waste incinerated. Linear dose response functions then estimate the change incidence in cancer and lost intelligence quotient (IQ) points per kilogram of heavy metal or dioxin ingested.

- For the second part of the equation, emissions of NOx, SOx, PM2.5 and PM10 are estimated using country emissions factors. Avoided emissions through energy recovery are accounted for to obtain the net metric tons of pollutant released.

b) **Disamenity, *from landfill and incineration sites:*** the total waste flow to landfills and incinerators per country is discounted over the site's remaining active years to get the present discounted waste flow to each landfill or incinerator site. Waste flows are discounted in order to reflect the higher effect of disamenity felt today than at periods in the future.

c) **GHGs, *from landfills and incineration:***

- Landfill GHGs are estimated over 90 years using the IPCC Waste Model, based on type of waste and the conditions of country landfills. The present value of associated impacts is then calculated by applying a social discount rate of 2%.

- Incineration GHGs are quantified using waste emission factors based on the fossil carbon content of the waste specified.

- Energy recovery are then accounted for both methods of disposal based on country data, to get net tons of CO_2 emitted.

d) **Leachate, *from landfills:*** countries are assigned a risk score[9] based on population density, soil permeability and percentage of sanitary landfills vs. unlined landfills or open dump sites within the country.

4.3 Monetary valuation

53. 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) **Air pollution, *from incineration*:** the valued impacts for air pollution are calculated through two means.

- Societal costs of cancer from dioxin exposure are estimated through a value of a statistical life and willingness-to-pay (WTP) studies. Cost of loss of IQ points through heavy metal exposure are estimated through WTP studies. Both are then applied as a valuation method to obtain the costs of health impacts resulting from waste incineration.

b) **Disamenity, *from landfill and incineration sites:*** The effect of the waste flow is valued by applying a hedonic transfer function, based on the national housing market, to represent the WTP to avoid disamenity.

c) **GHGs, *from landfills and incineration:*** both landfill and incineration GHGs are valued using the variety of methods described in the GHG Methodology.

d) **Leachate, *from landfills:*** A likelihood cost is used to estimate the worst-case cost scenario from a leachate incident. The worst-case cost scenario takes into account impacts on people through contaminated ground and surface water causing health impacts and reducing agricultural yields.

[9] Singh et al (2009).

5 Future Development

54. The Interim Waste Methodology represents the current state of knowledge built upon decades of rigorous scientific work. But some limitations still exist, including the ability of entities to have full visibility of their waste treatment outcomes and processing procedures. Comparable country-level waste data is also difficult to obtain, particularly for low-income countries or those with transitional waste management strategies. This limits the ability to provide robust and comparable value factors across countries.

55. There are opportunities to further advance waste impact accounting by exploring new pathways that overcome limitations and reduce uncertainty. Some of these include:

    a) New methods and tools that allow for a more complete and accurate accounting and reporting of entity waste data including added detail about the type of waste;

    b) Improvements in regulatory reporting on waste generation, which in turn may improve waste reporting;

    c) Incorporation of circular economy principles into the methodology that better capture the impacts associated with recycling and other circularity practices;

    d) Methodological updates that expand the scope of impacts included in the methodology such as topics like marine plastic waste;

    e) Improvements in waste disposal technologies, such as Landfill Gas Capture, or more stringent waste regulations, such as with open dump sites;

    f) Advancements to valuation approaches that can determine impacts at finer spatial resolution. For example, conditions at specific waste sites (e.g., climate and soil permeability) have a significant effect on the scale of waste impacts. Future work will continue to incorporate these considerations to refine water consumption valuation.

56. 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.

Appendix A: Glossary

Term	Definition	Source
Air pollution	The presence of harmful substances or particles in the air, caused by human activities or natural processes, that can have negative effects on human health, the environment, and climate.	WHO
Anaerobic	The conditions under which decomposition occur without oxygen. For landfill waste, this is when methane is then generated.	EPA
Anthropogenic	Caused or influenced by human activity.	National Geographic Society
Avoided emissions	A reduction or prevention of greenhouse gas emissions that would have occurred without specific actions or measures.	UNFCCC
Biogenic	A product made by, or from, life forms such as plants, animals and microorganisms.	EPA
Disamenity	A feature or factor that makes a location or property less desirable or unpleasant to be in, such as landfills or waste incinerators.	European Commission
Discount factor	A factor used to adjust future costs or benefits to their present value, taking into account the time value of money.	US Council of Economic Advisors
Ecosystem	A biological community of interacting organisms and their physical environment.	National Geographic Society
Energy recovery	The process of extracting usable energy from waste materials or by-products.	US Department of Energy

Environmentally extended input-output	An analytical framework that incorporates environmental data into economic input-output models to assess the environmental impacts of economic activities.	UNEP
Fossil carbon content	Contents of products that come from fossil fuels, such as plastics or synthetic textiles.	IPCC
Greenhouse gases	Gases, such as carbon dioxide and methane, that trap heat in the Earth's atmosphere and contribute to the greenhouse effect and global warming.	IPCC
Hazardous	A substance that poses a risk to human health, safety, or the environment due to its toxic, flammable, or otherwise dangerous properties.	World Bank
Hedonic pricing factor	A factor used in hedonic pricing models to estimate the implicit value of a specific attribute or characteristic of a good or service.	Office for National Statistics
Hedonic transfer function	A mathematical equation or model used to estimate the relationship between a good's attributes and its value.	University College London
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 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)
Incineration	The process of burning waste materials at high temperatures, often used for waste management and energy recovery.	World Bank
Life-cycle assessment	A comprehensive analysis of the environmental impacts of a product or process throughout its entire life cycle, from raw material extraction to disposal.	EPA
Landfill	A designated area for the disposal of solid waste, where waste is buried and covered with soil.	World Bank
Leachate	Liquid that drains or leaches through waste materials and may contain pollutants.	World Bank
Monetized impact	The process of assigning monetary values to damages.	N/A
Non-hazardous	A substance that does not pose a significant risk to human health, safety, or the environment.	World Bank
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)

Sanitary landfill	A landfill designed to minimize environmental impacts and prevent contamination of groundwater and soil with the presence of a liner.	EPA
Unlined landfill	A landfill without a protective liner to prevent leachate from contaminating the surrounding environment.	EPA
Valuation method	A technique or approach used to assign a monetary value to goods, services, or impacts for economic analysis or decision-making.	Office for National Statistics
Willingness to pay	A valuation method to assess the value of a good or service by how much people are willing to pay to experience it.	World Bank

Appendix B: Methodological Details

Introduction

B1. Defining waste management is a complex issue, covering a wide variety of materials, product types, and sources, yet all falling under the same umbrella as the 'unintended by-product of consumption and production'[10]. This lack of clarity as to what should be defined as 'waste', along with differing national conditions and data collection methods, make it difficult to arrive at clear definitions or easily comparable waste generation or treatment data[11]. The consequence is that the impact of waste is still largely not well reported, understood, or valued.

B2. However, as the awareness and reporting on climate change has improved globally, the recognition that waste plays a significant role in the triple planetary crisis of climate change, pollution and biodiversity loss has also grown. As such, the impacts of waste are starting to be better analyzed. Specifically, measuring and reducing the GHGs released from incinerated or decomposing waste are now priority regulations in many countries, along with reducing the amount of waste disposed in unsanitary or open dump sites[12]. Yet this means approaches for estimating the monetized impacts of waste vary in robustness for different impact pathways. The methodology therefore uses a variety of valuation method approaches for each of the impact pathways within the Interim Waste Model.

B3. The waste value factor is determined by summing the monetized impacts across four pathways:

$$WVF_{ti} = AP_{ti} + Dis_{ti} + GHG_{ti} + L_{ti}$$

Where AP = air pollution, Dis = disamenity, GHG = greenhouse gases and L= leachate. The specific calculations of these modules are set out below (each module calculates the impacts associated with a specific impact pathway).

Air pollution module

B4. This module values the impacts associated with air pollution from incineration. As landfills produce trivial volumes of non-GHG emissions they are not addressed here. The air pollutants from incineration fall into two categories within the Interim Waste Model: heavy metals and dioxins, and traditional air pollutants (NOx, SOx, PM2.5 and PM10).

[10] UNEP – Beyond an Age of Waste – Global Waste Management Outlook, 2024.

[11] UNEP – Beyond an Age of Waste – Global Waste Management Outlook (2024).

[12] EU Landfill Directive (2018), South Africa Control of Waste Disposal Sites By-Law (2007).

B5. The air pollution valuation formula is as follows:

$$AP_{ti} = (health\ incidences\ per\ kg\ heavy\ metal_{ti} \times kg\ heavy\ metal\ per\ pollutant_{ti}) + (Gross\ pollutant\ emissions_{ti} - avoided\ emissions_{ti})$$

a) The impact of heavy metals and dioxins is valued through health impacts: the majority are highly damaging to health and, if inhaled, can cause cancer or neurotoxicity, reducing IQ. First, heavy metal and dioxin emissions released per metric ton of waste incinerated are calculated using regional emissions limits on waste incineration[13]. Dose response functions then describe how many health effects are likely to be associated with a given level of emissions. Dose response functions in terms of cancers per kg of dioxin, and neurotoxicity per kg of heavy metal are taken from ExternE (2004). These incidences of health impact are then valued through two methods:

- Of the cancers caused, a proportion are assumed to be fatal and non-fatal cancers[14]. For fatal cancers, the value of a statistical life[15] is used to estimate the impact value. For non-fatal cancers, a median WTP from studies to avoid non-fatal cancer is applied.[16]

- For neurotoxicity, a median WTP is taken from studies to avoid a loss of 1 IQ point.[17]

These provide a single global value for health impacts, with the option to adjust values for country income. This represents the total monetized impact of heavy metals and dioxins.

b) For traditional air pollutants, the methodology calculates the total emissions released before subtracting any avoided emissions from energy recovery. Total emissions are estimated using global emissions factors[18] for 1 metric ton of industrial waste incinerated. Avoided emissions through energy recovery are then estimated using the emissions intensity of the national grid for the relevant

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[13] See EMEP/EEA Air Pollutant Emission Inventory Guidebook (2023).

[14] Cancer survival statistics, Cancer Research UK (2024).

[15] IFVI VoSL value.

[16] See OECD (2011).

[17] Spadaro, J. and Rabl, A. (2004).

[18] See EMEP/EEA Air Pollutant Emission Inventory Guidebook (2023).

pollutant in each country. Once the net volumes of these air pollutants are calculated, the Interim Air Pollution Methodology value factors are applied to calculate the social cost of the impact.

c) These valuation of these two impacts are added together to generate the total monetized impact of air pollution from waste incineration.

Disamenity module

B6. This module values the disamenity associated with waste disposal, including visual intrusion, noise, odor, and pests. The approach for valuing disamenity through hedonic pricing is well established and as such is the method followed here. In this approach, disamenity impacts are valued based on the impact of proximity to a landfill or incineration site on observed house prices.

B7. The disamenity valuation formula is as follows:

$$Dis_{ti} = \frac{Fn}{\sum_{1}^{T} W/(1-DR)^{y}}$$

Where:

F = hedonic function transfer

n = number of waste sites per country

W = annual national waste to landfill / incinerator

DR = discount rate

y = remaining site lifetime (years)

a) This module uses a linear hedonic price function (HPF, or F in the valuation formula), reflecting that the change in house price as a function of its distance from a waste management facility. This was derived from the results of a meta-analysis of hedonic pricing studies from Schutt et al (2021),[19] using the hedonic pricing function approach as described by Eunomia (2002).[20]

b) The HPF is adjusted for country differences by accounting for country-specific factors, such as average property price and household density, along with total number of disposal sites within the country. This function represents the WTP to

[19] Schutt et al (2021).

[20] Eunomia (2002).

avoid all disamenity effects of disposal sites adjusted for country-specific socio-economic factors.

c) Finally, to get the disamenity impact per metric ton of waste, the disamenity impact is apportioned across each metric ton of waste entering the disposal site over its remaining lifetime. The total metric tons of waste entering landfills or incinerators per country is discounted over the remaining lifetime of those sites at a rate of 2%. Waste flows are discounted in order to reflect the higher effect of disamenity felt today than at periods in the future. The disamenity associated with each metric ton of waste is therefore the total WTP to avoid disamenity from waste disposal sites in a country, divided by the discounted waste flow to that site.

GHGs module

B8. The Intergovernmental Panel on Climate Change's (IPCC) National Greenhouse Gas Inventories[21] provides a global standard for calculating and reporting on entity GHGs. Chapter 5 of the Inventories provides methodologies for estimating the emissions from incineration and decomposition (in landfills) of waste. As such, these methodologies are used to calculate landfill and incineration GHGs from waste disposal.

B9. Both the incineration and landfill GHGs calculations follow the same methodology format: the total emissions released from the respective waste treatment are calculated along with the avoided emissions through energy recovery programs within the country. Total emissions and avoided emissions can then be summed to quantify the net emissions released. These net emissions are then valued with the Social Cost of Carbon (see further details on the SCC in the *Greenhouse Gas Emissions Topic Methodology*).

B10. The GHG valuation formula for both landfill and incineration is as follows:

$$GHG_{ti} = gross\ emissions\ released_{ti} - avoided\ emissions_{ti}$$

a) The IPCC Waste Model[22] is used to estimate the total amount of GHGs released from 1 metric ton of waste being disposed in a landfill, designed for use in calculating country GHG emission's inventories. Landfill GHGs are generated through the degradation and decomposition of waste under the anaerobic conditions that prevail in landfill sites. The primary gas released from this decomposition is methane (CH_4), which is emitted over the lifetime of the landfill – the IPCC recommends calculating this over 90 years as beyond this, emissions are insignificant.[23] The IPCC

[21] IPCC Guidelines for National Greenhouse Gas Inventories

[22] IPCC Guidelines for National Greenhouse Gas Inventories, IPCC Waste Model.

[23] IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 5: Waste.

Model used in this methodology allows for adjustments depending on the conditions present in the landfill (e.g. different climatic conditions), as well as the characteristics of waste, to generate total methane released per metric ton of waste disposed in a landfill per country. Once total methane generated has been calculated, it is converted into CO2e and the avoided emissions from energy recovery programs within individual countries is subtracted from this to yield the net CO2e released over the landfill lifetime.

b) Incineration GHGs are generated through the CO2 released from the burning of waste. Some of this CO2 is biogenic, such as wood or plant matter, which forms part of the carbon cycle. However, this module is concerned with the anthropogenic emissions released when fossil carbon, or carbon that would otherwise stay out of the carbon cycle, is released. Fossil carbon released per metric ton of incinerated waste is estimated as a product of the carbon content of waste, of which what percentage is fossil carbon, and the efficiency of combustion of such waste. The IPCC default values for calculating national GHG emission inventories are taken for these variables[24], however if these variables are known then these figures should be used instead (see the Waste User Guide).

c) For both landfill and incineration GHGs, once the total amount of CO2/CO2e released is known, the impacts are valued using the SCC. For Landfill GHGs, the SCC is inflated at a rate of 1.5%[25] over 90 years and then discounted at a rate of 2% to get the net present valued impact of Landfill GHGs. For Incineration GHGs, where the emissions are instantaneous and not emitted over many years, the net tons of CO2 emitted are multiplied by the year of emission's SCC.

Leachate module

B11. This module values the societal impacts of leachate release. As leachate is a by-product only from landfill, incineration treatment is not considered here.

B12. As with other areas in this methodology, a methodology ideally would apply a specific impact pathway approach to the causal links between disposal of waste and impacts of leachate on, say, drinking water and agriculture via groundwater. However, there is no credible generalizable approach to do this given that occurrence of leachate is highly site-

[24] IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 5: Waste – Table 5.6.

[25] UK Department for Business, Energy and Industrial Strategy, Policy Paper: Valuation of greenhouse gas emissions: for policy appraisal and evaluation, September 2021.

specific and typically occurs over a long period of time. This module instead uses a risk-based approach typically used in valuation approaches[26].

B13. The leachate module valuation formula is as follows:

$$L_{ti} = \ worst\ case\ cost \times country\ risk\ factor_{ti}$$

a) A risk-adjusted estimate of the likelihood of a leachate incident occurring in a country is estimated using the HARAS model[27]. This leachate risk factor is based on three characteristic ratings: source of waste (hazardous vs. non-hazardous), pathway (soil permeability of site), and receptor (population density around site), along with whether the landfill is sanitary or unlined. This represents the likelihood and severity of a leachate incident per country, ranked on a scale from 0 (no risk) to 1000 (high risk).

b) To then estimate the monetized value of leachate impacts, clean-up costs are used as a proxy for societal costs. Clean-up cost is the chosen valuation approach as estimating the impacts of leachate in a given location is subject to high uncertainty. The Onalaska Municipal Landfill in Wisconsin is likely to be a good proxy of the worst case societal impact as over the period the landfill was active (1969-1980) a mixture of municipal and hazardous wastes were disposed of, including a relatively high proportion of chemical wastes. The site was unlined, in an area of high soil permeability, and affected a relatively large population. This chosen cost represents a ‘worst case’ scenario, given per metric ton of waste disposed, as defined in the HARAS model with a score of 1000. This is then applied to country-specific HARAS rankings and adjusted for country PPP.

Combining all monetized impacts

Once all impact pathways have been monetized, these are combined to create value factors for each waste type (hazardous or non-hazardous) and treatment type (landfill or incineration), for every country. Where waste treatment is unknown, the methodology applies an “unspecified” treatment value factor by taking a worst-case value factor, i.e. whichever is higher of the landfill or incineration value factor in a given country.

[26] Miranda and Hale (1997).

[27] Singh et al (2009).

Appendix C: Value Accountability Framework – Value Factors

This Appendix presents the Interim Waste 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 Waste Topic Methodology Value Factor, Version 1

Developed by: International Foundation for Valuing Impacts

Published and updated date: October 2024</td></tr>
<tr><td colspan="3">Unit: The impact in dollars per metric ton ($/metric ton) of waste, hazardous or non-hazardous, being sent to landfill, incineration or unspecified, per country.</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.</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 hazardous or non-hazardous waste being sent to landfill or incineration.

2. The value factor captures impacts associated with waste disposal including from air pollution, greenhouse gases, disamenity effects and leachate. Future work will continue to explore the valuation of additional 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 MONETARY VALUE</th></tr>
<tr><td>Approach and specificity</td><td>5. Via four impact pathway modules (air pollution, disamenity, GHGs, and leachate) changes in well-</td><td>10. For each of the changes in well-being pathways, societal impacts are estimated using different valuation methods.</td></tr>
</table>

	being are estimated using a series of economic techniques. 6. The changes in well-being are estimated through health impacts (morbidity and mortality) from air pollution, hedonic pricing transfers from waste disposal sites for disamenity, social costs of carbon of GHGs and potential clean-up costs for leachate. 7. The Interim Waste Model has data inputs for many countries and models impacts at the national level, or regional level where national data are not available. 8. Present research has not yet captured all impacts on society and future work will continue to develop value factors for these impacts. 9. Additional details about estimating changes in well-being can be found in Section 4.2: Outcomes and Impacts and Appendix B: Methodological Details.	11. The approaches to convert impacts into monetary terms can be found in Appendix B: Methodological Details. 12. Where future impacts are modelled (Disamenity and Landfill GHGs), present day values are discounted at a 2% social discount rate. 13. Waste impacts can be highly localized, however as specific waste data are hard to obtain, impacts have been averaged at a national, or regional level, where needed. 14. Additional details about estimating societal impacts can be found in Appendix B: Methodological Details.
Data inputs	15. Country-specific and regional-income waste data is taken from the World Bank and UNEP. 16. For further data sets see Appendix B: Methodological Details along with the primary literature sources cited in each.	
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.	
ETHICAL DECISIONS IN ESTIMATING SOCIETAL IMPACT		

Equity weightings and income adjustments	18. The health impacts of waste disposal use a global DALY value to ensure equity in consideration of impacts regardless of their location.
Accounting for future impacts	19. Future impacts are modelled in the Disamenity discounted waste flow and Landfill GHG methane release. Both are discounted at a rate of 2%, and the SCC is assumed to grow at a rate of 1.5% per year.
Other ethical considerations	20. N/A
SENSITIVITY	
Sensitivity to key variables	21. Sensitivity analysis was carried out for hazardous and non-hazardous waste to landfill and incineration, for 3 countries (United States, China and Nigeria). For full results see Table 2.

Table 3: Sensitivity analysis

Key: HL – Hazardous waste to landfill, HI – Hazardous waste to incineration, NHL – Non-hazardous waste to landfill, NHI – Non-hazardous waste to incineration

		United States				**China**				**Nigeria**			
Variable	**Flex**	*HL*	*HI*	*NHL*	*NHI*	*HL*	*HI*	*NHL*	*NHI*	*HL*	*HI*	*NHL*	*NHI*
SCC	10%	8%	10%	9%	9%	7%	9%	8%	7%	7%	10%	8%	9%
Waste type	Textile (from industrial)	23%	0%	26%	0%	19%	0%	22%	0%	19%	0%	21%	0%
Leachate clean-up cost	10%	1%	0%	0%	0%	1%	0%	0%	0%	1%	0%	0%	0%
Lined landfill	10%	11%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%
House price	10%	1%	0%	1%	0%	2%	1%	2%	2%	0%	0%	0%	0%
Household density	10%	-1%	0%	-1%	0%	-1%	-1%	-2%	-2%	0%	0%	0%	0%
Hedonic factor	10%	1%	0%	1%	0%	2%	1%	2%	2%	2%	0%	2%	0%
Value of IQ point	10%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Income adjustment for health	Income adjusting health impact	0%	0%	0%	0%	0%	-1%	0%	-2%	0%	-1%	0%	-2%

Appendix D: Data Sources in the Interim Waste Methodology

Data	Source[28]	Year
ERQ Score	Esty (2002)	N/A
Sox intensity of national grid	Ember	2024
Nox intensity of national grid	Ember	2024
PM2.5 intensity of national grid	Ember	2024
PM10 intensity of national grid	Ember	2024
Average CO2e grid factor	Ember	2024
Emissions factors	EMEP/EPA	2024
Soil permeability	Gleeson 2011	2024
Household size	United Nations Population Division	Various
Total waste metric tons	World Bank	2024
Landfill waste flow	World Bank	2024
Metric tons landfill waste flow	World Bank	2024
Incineration waste flow	World Bank	2024
Metric tons incineration waste flow	World Bank	2024
Waste collection	World Bank	2024
Average property price	Finder	2022
IPCC climate zones	IPCC	2000

[28] Sources are hyperlinked for your reference.

Non-hazardous -fraction methane captured	World Bank	2024
Non-hazardous fraction captured methane then burned	World Bank	2024
Hazardous-fraction methane captured	World Bank	2024
Hazardous - fraction captured methane then burned	World Bank	2024
Dioxin EF (g I-TEQ/Mg waste)	EEA	2023
Pb EF (g I-TEQ/Mg waste)	EEA	2023
Hg EF (g I-TEQ/Mg waste)	EEA	2023
Hazardous waste incineration with energy recovery	World Bank	2024
Non-hazardous waste incineration with energy recovery	World Bank	2024
% lined landfills - Australia	Government statistics	2013
% lined landfills - Australia	Waste Management Association	2008/2010
% lined landfills - India	Delhi Pollution Control Board	2020
% lined landfills - Morocco	World Bank	2013
% lined landfills - Pakistan	Centre for Peace and Development Pakistan	2021
% lined landfills - Peru	Holland Circular Hotspot	2021
% lined landfills - Russia	World Bank	2010
% lined landfills - Tunisia	EEA	2013
% lined landfills - Turkey	EEA	2013

% lined landfills - Chile	Holland Circular Hotspot	2021
% lined landfills - Singapore	Government statistics	2021
% lined landfills - Thailand	Chiemchiasri et al	2008
% lined landfills - Vietnam	Thiemialis et al	2005
% waste to landfill - Bangladesh	Government statistics	2022
% waste to landfill - Colombia	Holland Circular Hotspot	2021
% waste to landfill - Mauritius	Government statistics	2019
% waste to landfill - Mexico	Holland Circular Hotspot	2021
% waste to landfill - Norway	Norway Statistics Centre	2018
% waste to incinerated - Brazil	da Silva et al	2020
% waste to incinerated - OECD	OECD Statistics	2022
Number of landfills- Albania	EEA	N/A
Number of landfills- Cambodia	Pheakdey et al	2022
Number of landfills- Brazil	World Bank	2004
Number of landfills- Canada	Government statistics	2020
Number of landfills- Chile	National report	2020
Number of landfills- Colombia	European Union statistics	2018
Number of landfills- Croatia	Netherlands Foreign Office	2022
Number of landfills- Denmark	Government statistics	2015
Number of landfills- Finland	EastCham Finland	2020
Number of landfills- France	Zero Waste France	2015
Number of landfills- Iceland	EEA	2016

Number of landfills- Jordan	Retech Germany	2013
Number of landfills- Malaysia	Greenpeace	2024
Number of landfills- Morocco	WWF	2019
Number of landfills- Russia	Semenova et al	2020
Number of landfills- South Africa	Government statistics	2016
Number of landfills- Thailand	Government statistics	2021
Number of landfills- Turkey	Government statistics	2020
Number of landfills- UK	Government statistics	2024
Number of landfills- US	Government statistics	2024
Number of landfills- Vietnam	Salhofer et al	2022
Number of incinerators - Albania	Policy Paper	2019
Number of incinerators - Australia	Zero Waste Australia	N/A
Number of incinerators - Canada	Government statistics	2022
Number of incinerators - Finland	Government statistics	2015
Number of incinerators - Germany	Government statistics	2019
Number of incinerators - Iceland	Oskarrson et al	2022
Number of incinerators - Japan	Government statistics	2022
Number of incinerators - Jordan	UNDP	2020
Number of incinerators - Malaysia	Yong et al	2020
Number of incinerators - Netherlands	Zero Waste Europe	2018
Number of incinerators - Russia	Shilkina et al	2018

Number of incinerators - Thailand	IPEN	2006
Number of incinerators - UK	UKWIN	2022
Number of incinerators - US	National Research Council	2000
Number of incinerators - Vietnam	Salhofer et al	2021
Cancers / IQ loss per kg of heavy metal	Spadaro & Rabl	2008
Cancers / IQ loss per kg of heavy metal	Rabl et al	2008
WTP avoid lost IQ	OECD	2023
WTP avoid of cancer	OECD	2004
Cancer survival	Cancer Research	2022
Conversion calculator	EPA	2024
IPCC Waste Model	IPCC	2000
Hedonic pricing function	Schutt et al	2021
Hazardous Waste incinerated	UN Data	2023
Carbon content of waste	IPCC	2000
HARAS scores	Singh et al	2012
SCC Annual growth rate	UK Government	2021
OECD GNI	OECD	2022
Remaining site lifetime	South Carolina State Environment Department	2019
Remaining site lifetime	Michigan Department for environment	2022
Carbon CO2 conversion	EPA	2024

Health cost elasticity	Viscusi and Masterman	2017
Onalaska Case Study	US EPA	1990
Energy potential of waste incineration	Kumar & Samadder	2022
Energy potential of waste landfill	Dadario et al	2023

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INTERIM METHODOLOGY

Water Pollution

Environmental Topic Methodology

The International Foundation for Valuing Impacts, Inc. (IFVI) is a section 501(c)(3) public charity dedicated to building and scaling the practice of impact accounting to promote decision-making based on risk, return, and impact.

Table of Contents

Executive Summary

- The Interim Water Pollution Topic Methodology can be used by preparers of impact accounts to measure and value the impact of water pollution on people and the natural environment. The Interim Water 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 water pollution across an entity and its value chain

    - organize water pollution data by pollutant, and location, including whether it is discharged into seawater, freshwater, or unspecified;

    - utilize the impact pathway and value factors developed in this methodology to convert water 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 Water 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 water pollution include reduced human health, reduced recreational and property value, and impacts from reduced fish stocks.

- **Section 3** establishes the data required from the entity to implement the Methodology. This includes water pollutants produced in kgs by location, organized by whether they are discharged into freshwater, seawater, or unspecified.

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

- **Section 4** outlines the approach of the Methodology for measuring and valuing the impacts, focusing on research linking the direct impacts of water pollutants on human health and the broader impacts of eutrophication.

- **Section 5** articulates potential opportunities for further development of the Methodology.

- This Interim Water Pollution 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 Methodology for Water Pollution (henceforth, the Interim Water 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 Water 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 Water Pollution Methodology can be used to inform internal decision-making, investment decisions, and understand the significance of waste 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 Water Pollution Methodology can be applied via this document and the Global Value Factors Database. Supporting resources include the Interim Water Pollution Methodology Model and the 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 Water 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. For the purposes of the Methodology, water pollution is defined as the release of substances into surface water, such as lakes, streams, rivers, estuaries, and oceans, or

into subsurface groundwater to the point that the substances interfere with the beneficial use of the water or with the natural functioning of ecosystems.[2]

8. Water pollution is a global issue that is on the rise, despite improvements in some developed countries. It has adverse effects on human well-being and carries a societal cost. Unsafe water kills more people each year than war and all other forms of violence combined.[3] Meanwhile, drinkable water sources are finite: less than 1 percent of the earth's freshwater is actually accessible to humans. Without action, the challenges will only increase by 2050, when global demand for freshwater is expected to be one-third greater than it is now.[4]

9. The impacts of water pollution are primarily local or regional and depend on the physical environment and local demographic exposure. For example, the change in concentration of arsenic following a release depends on the size of the water body and flow rate. The extent of its subsequent impact on people depends on the likelihood that local populations will come into contact with the polluted water.

10. The most significant categories of water pollutants are toxic pollutants, nutrient pollutants, pathogens, and thermal pollution.

11. Toxic pollutants[5] are substances or combinations of substances which after discharge and upon exposure, ingestion, inhalation, or assimilation into any organism result in adverse effects. They include both organic and inorganic substances and have a tendency to bioaccumulate in the food web, persist in the environment, and cause undesirable changes in the natural environment. These pollutants can enter water bodies through industrial discharges, agricultural runoff, and improper waste disposal.

12. Nutrient pollutants, such as nitrogen and phosphorus, can lead to excessive plant and algal growth in a process known as eutrophication. These nutrients, which originate from sources like agricultural fertilizers, sewage, and stormwater runoff, are essential for life. However, in elevated concentrations, they can cause severe algal growth, resulting in a range of negative effects, such as low levels of dissolved oxygen in the

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[2] Britannica (2016). *Water Pollution sources and impacts.*

[3] NRDC (2023). *Natural Resources Defense Council. Water Pollution: Everything You Need to Know*.

[4] UNESCO World Water Assessment Programme (2018). *The United Nations world water development report 2018: nature-based solutions for water.*

[5] Cornell Law School 33 U.S. Code § 1362 – Definitions. *The term "toxic pollutant" means those pollutants, or combinations of pollutants, including disease-causing agents, which after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will, on the basis of information available to the Administrator, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction) or physical deformations, in such organisms or their offspring.*

water. This then leads to hypoxic conditions that can kill fish, crabs, oysters, and other aquatic animals.[6]

13. The impact of eutrophication extends beyond aquatic life. Harmful algal blooms, particularly those caused by cyanobacteria, produce toxins hazardous to human health. Eutrophication also results in secondary impacts such as impaired recreational value and decreased property values. Excessive macrophyte growth due to nutrient enrichment can make water bodies less suitable for recreational use by creating health hazards from toxic blooms, water congestion from vegetative growth, unfavorable appearances, and unpleasant odors. This subsequently affects the potential sale value of local properties.[7] Studies suggest that leisure and residential properties can be devalued by as much as 20% due to consistently poor physical water quality.[8] Additionally, hypoxic conditions resulting from excess algal growth can lead to a decline in fish stocks and the accumulation of toxins in fish, negatively impacting commercial fishing and exacerbating economic losses.

14. Understanding and addressing water pollution is crucial on a global scale. The high-level impacts include not only environmental degradation but also significant economic and health concerns. Measuring these impacts is essential for developing effective strategies to mitigate water pollution.

15. The Methodology takes a societal perspective rather than a discrete affected stakeholder group by considering the impacts on society, both within the region where water is polluted and globally. By measuring and valuing the impacts on society, water pollution impact accounts can provide guidance to entities to manage and mitigate risks.

16. While the Methodology measures the impacts of an entity on stakeholders, understanding and managing water pollution impacts can also help an entity comply with environmental regulations, reduce the risk of legal action, enhance the entity's reputation, and improve operational efficiency by preventing contamination-related shutdowns and remediation expenses.

1.3 Scope and assumptions

17. The health impacts of toxic pollutants are comprehensively covered in the Methodology. These pollutants include both inorganic substances, such as heavy metals and organic compounds such as Benzene, and Polycyclic aromatic hydrocarbons, which

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[6] National Ocean and Atmospheric Administration. *Ocean Facts. What is Nutrient Pollution?*

[7] Krysel, C., Boyer, E. M.; Parson, C.; Welle, P. (2003). *Lakeshore Property Values and Water Quality: Evidence from Property Sales in the Mississippi Headwaters Region.*

[8] Wood, R. and Handley, J. (1999). Urban waterfront regeneration in the Mersey Basin, North West England.

can persist in the environment, bioaccumulate in the food web, and cause adverse health effects.

18. While there are studies that assess the societal costs of both organic and inorganic pollutants, comprehensive comparative studies that evaluate the relative societal costs of different pollutants and pathways in a way that can fully inform whether impacts are significant. The Methodology aims to cover as many pollutants and pathways as possible, only excluding areas where there is particularly strong evidence of immateriality, insufficient data, or a compelling case on other grounds.

19. The Methodology does not address ecotoxicity due to the preliminary stage of research in this area, and the increasing number of (unknown) chemical stressors and mixture effects present in the environment. The European Commission, for example, has indicated that substantial work is still needed to robustly consider the toxicity effects on biodiversity and consequently on recreation, property values, fish stocks, livestock, agriculture, and other ecosystem services.[9]

20. Thermal pollution, which involves the discharge of water at temperatures different from the ambient water bodies, is also out of scope in the Interim Water Pollution Model. The impacts of thermal pollution are highly localized, and there is no consistent data collected to clearly articulate the causation in an impact pathway. However, it is recognized as an issue for some industries and can be addressed on a case-by-case basis in future methodologies.

21. The Methodology does not address groundwater contamination due to the lack of a suitable model for understanding the relationships between discharges, changes in groundwater quality, and human consequences.

22. The health impacts of pathogens are not considered within the scope of this methodology. This exclusion is based on two reasons: human wastes are less commonly directly linked to corporate activities, and the impacts of consuming water containing harmful pathogens are captured in the Water Consumption Methodology, and therefore the risks of double-counting of impacts would be high.

23. The methodology uses USEtox[10] to model chemical date and exposure of humans to toxic pollutants. USEtox includes a number of simplifying assumptions, as explained

[9] European Commission-Joint Research Centre (2011) - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) *Handbook- Recommendations for Life Cycle Impact Assessment in the European context*.

[10] Rosenbaum, R.K., Huijbregts, M.A.J., Henderson, A.D., Margni, M., McKone, T.E., van de Meent, D., Hauschild, M.Z., Shaked, S., Li, D.S., Gold, L.S., Jolliet, O., (2011). *USEtox human exposure and toxicity factors for comparative assessment of toxic emissions in life cycle analysis: sensitivity to key chemical properties.* USEtox was developed by

within its documentation. Key assumptions and simplifications include the use of country geophysical parameters for a location (e.g. average temperature, average rain rate, average freshwater depth) and linear dose response functions. This assumes that pollutant concentrations are already above any damage threshold, such that any addition of pollution in the environment causes an impact.

24. The scope and boundaries of the Interim Methodology includes full value chain water 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 water pollution production may be based on models and not directly measured due to the challenges of measuring upstream and downstream water pollution.

25. The Interim Water Pollution Methodology recognizes full responsibility of an entity for its upstream and downstream waste production. Water pollution is attributed to an entity through physical or economic relationships by portioning the inputs or outputs of water pollution and determining the portion that is linked to the entity. The inclusion of value chain water 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.

1.4 Key concepts and definition

26. For the Methodology, the following terms are defined as follows:

    a. Eutrophication: This refers to the process by which a body of water becomes overly enriched with nutrients, leading to excessive growth of algae and other aquatic plants. This can result in oxygen depletion and harm to aquatic life.[11]

    b. Ecosystem services: The benefits that humans receive from ecosystems, including provisioning, regulating, cultural, and supporting services. The valuation of these services can be impacted by water pollution.

    c. Willingness to pay (WTP): A measure of the amount individuals are willing to pay to avoid negative outcomes, such as health impacts from water pollution. This is used in the valuation of societal costs of emitting excess nutrients to water.

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the Task Force on Toxic Impacts under the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative to include the best elements of available LCA multi-media models.

[11] F. Chislock, E. Doster, A. Zitomer (2013) *Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems.*

d. Disability-adjusted life year (DALY): A measure used to quantify the burden of disease. It represents the total number of years lost due to ill-health, disability, or early death. The value of a DALY is used to put a monetary value on the damage function calculated in DALYs per case.

2 Impact Pathway

2.1 Summary

27. 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.

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

29. The impact pathway for water pollution is as follows:

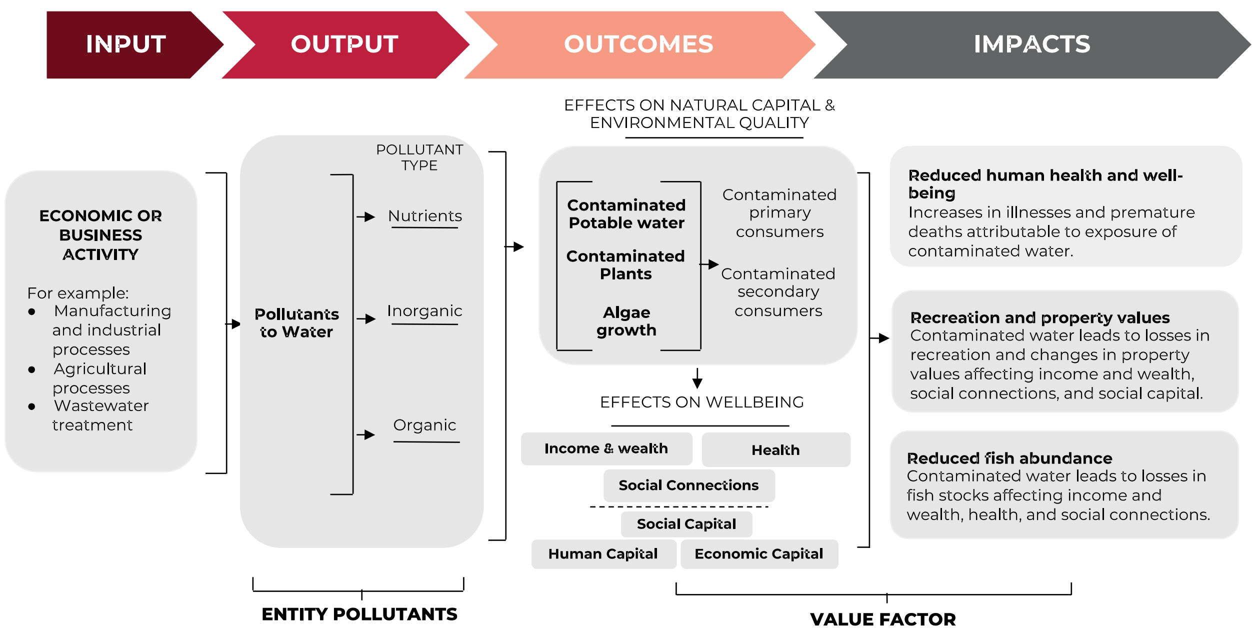

Figure 1: Water Pollution impact pathway

2.2 Description and notes

30. The primary inputs for the water pollution impact pathway are the corporate activities that generate water pollution including industrial processes, agricultural activities, and wastewater treatment. For instance, industrial processes may release heavy metals and chemical compounds into water bodies, while agricultural activities contribute nutrients such as nitrogen and phosphorus through runoff. Wastewater treatment plants, although designed to clean water, may still discharge pollutants if the treatment is not fully effective.

31. The output from these corporate activities can be categorized into various types of pollutants. These include inorganic pollutants (e.g., heavy metals like arsenic and mercury), organic pollutants (e.g., chemical compounds), and nutrients (e.g., nitrogen and phosphorus).

32. The disposal and accumulation of these pollutants have consequent impacts on environmental quality and natural capital. These include contamination of potable water, plants, and livestock; eutrophication due to excess nutrients; and bioaccumulation of pollutants in the food web. The likelihood of these impacts being realized is greatly influenced by the type and concentration of pollutants discharged.

33. The consequential changes to the physical environment drive impacts that reduce the well-being of people and the condition of the natural environment. Categories of well-being affected include income and wealth, health, social connections, social capital, human capital, and economic capital. These primarily fall in two categories in the Interim Water Pollution Methodology:

    a. Human health impacts: Toxic pollutants discharged into water systems can persist in the environment, bioaccumulate in the food web, and cause adverse health effects ranging from acute illnesses, such as gastrointestinal diseases, chronic conditions such as cancer, and neurological disorders, and DALYs lost.

    b. Impacts to Recreation, Property Values, Fish Stocks, Livestock, Agriculture, and Ecosystem Services. Nutrient pollutants discharged to water systems in excess resulting in eutrophication can impair recreational opportunities such as swimming, fishing, and boating. This loss in recreation not only affects the well-being of individuals but also has economic implications for communities that rely on tourism and recreational activities. Properties located near water bodies with severe algal growth often experience a decline in value. This is attributable to the reduced aesthetic and recreational value of the water, as well as potential health risks associated with living near contaminated water sources. Hypoxic conditions in water bodies as a result of eutrophication can lead to a decline in fish stocks, affecting both commercial and subsistence fishing. Moreover, toxins can accumulate in fish, making them unsafe for consumption and reducing their market value. This has direct economic impacts on the fishing industry and communities that depend on fishing for their livelihood.

3 Impact Driver Measurements

34. Impact drivers consider inputs and outputs and reflect the data needs expected of a preparer to provide an impact account for water pollution. The section below outlines the specific data needed along with how these data align with various respective reporting standards.

35. Data requirements for the Interim Water Pollution Methodology are aligned with and expand upon water pollution related sustainability reporting standards, which primarily capture quantities of water discharged to particular water sources and specific water pollutants of concern.

3.1 Data requirements

36. The Interim Water Pollution Methodology requires the total kilograms of each pollutant released to freshwater or seawater as presented in Appendix E and featured in the Global Value Factor Database. These measures should be separated by country, as shown in Table 1. If it is not known whether a pollutant is released to freshwater or to seawater, an 'unspecified' value factor can be used.

37. Companies will need to select the water pollutant that are relevant to their business, including their direct operations and full upstream and downstream value chain.

Data input		Country	Country 2	Country 3
Water Pollution in Own Operations				
Pollutant mass released to water (kg)	Freshwater			
	Seawater			
	Unspecified			
Water Pollution in Upstream Value Chain				
Pollutant mass released to water (kg)	Freshwater			
	Seawater			
	Unspecified			
Water Pollution in Downstream Value Chain				
	Freshwater			

Pollutant mass released to water (kg)	Seawater			
	Unspecified			

Table 1: Water pollution data requirements

38. Due to the exhaustive nature of water pollutants included in the Methodology, not all are listed in the chart above. A full list is available in Appendix E and the Global Value Factors Database.

39. The data requirements of the Water Pollution Topic 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 303: Water and Effluents 2018. Additional alignment may exist with other regional or topic specific reporting standards as well.

Metric	ESRS	GRI
Water Pollution – own operations	Expands upon E2-4, paragraph 26 and 28, page 108	Expands upon Disclosure 303-4 (a) and (d)
Water Pollution – value chain	Expands upon E2-4, paragraph 26 and 28, page 108	Expands upon Disclosure 303 -4 (a) and (d)
Location of waste production	Expands E2-4, paragraph 26 and 28, page 108 Expands upon E2-4, paragraph AR 22, page 112	Expands upon Disclosure 303-4 (a) and (d)
Water Type Polluted	Aligns with E2-4, paragraph 26 and 28, page 108 Expands upon E2-4, paragraph AR 22, page 112 Table 2 – Terms defined in the ESRS, Annex II, page 23 and 28	Expands upon Disclosure 303 -4 (a) and (d)

Table 2: Alignment with reporting standards[12]

[12] 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.

3.2 Data sources, gaps, and uncertainty

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

41. In practice, obtaining full value chain water 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, water pollution impacts.

42. To determine the impacts of waste, total mass of water pollutants, split by compound, destination (seawater vs freshwater vs unspecified), and by location (at least country-level). These can be estimated directly, using data reported by the entity, or indirectly through techniques such as Life-cycle Assessment or Environmentally Extended Input-Output Modelling. Where a direct approach is taken, water pollution data should be apportioned to seawater vs freshwater using actual data where available. Otherwise, general trends at a country or sub-national level can be used.

43. To determine water pollution, knowledge of water pollutant type, discharge quantities and pollutant concentration is necessary. Water discharge data is often more difficult to obtain as water utilities often do not monitor it. If an entity is not directly measuring discharge, it will need to be estimated from secondary data.

44. The metric data required are the masses of each pollutant emitted to water from a given source location in a given year. Measurement of discharges to water is best undertaken on-site using direct in-line measurement. However, aside from large, regulated facilities in developed countries, this is rarely a practical data source, and instead the drivers of pollution to water can be measured to estimate discharges indirectly.

45. Preparers should prioritize approaches that:[13]

    a. directly measure waste produced over those that estimate waste production 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.

46. High quality data sources should consider:[14]

    a. technological representativeness. Does the data match the technology used?

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[13] Language adapted to water consumption from the Greenhouse Gas Protocol. (2011). Corporate value chain (scope 3) accounting and reporting standard.

[14] Language adapted to water consumption from the Greenhouse Gas Protocol. (2011). Corporate value chain (scope 3) accounting and reporting standard.

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?

47. Various estimation techniques can be used to determine water pollution. While a variety of techniques exist, those recommended for water pollution analysis include life cycle analysis (LCA) and environmentally extended input-output (EEIO) tables. Both approaches have developed frameworks for determining water pollution but may differ in levels of data specificity or considerations depending on the context of application.

48. Uncertainty will arise when quantifying water pollution. Preparers should report qualitative uncertainty and, when possible, quantitative uncertainty. These may include but are not limited to propagated measured uncertainty, pedigree matrices, 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.[15]

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

4 Outcomes, Impacts and Valuation

49. The impacts that result from water pollution affect the environmental quality dimension of well-being and the well-being resource of natural capital. These are linked to the well-being of people through their effects on health, income and wealth, social connections, as well as social, human, and economic capital.

50. The impact pathway in this statement has been developed using a value factor that collapses the impact measurement and valuation stages into a summary value that is location-specific for each category of impact. The value factors, available in the GVFD can then be multiplied directly by entity-specific waste production consumption 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

51. To determine the monetized health and eutrophication impacts of water pollutants (WP $\text{Value}_{\text{Total}}$), entities should apply the following valuation formula:

$$\textbf{WP Value}_{\textbf{Total}} = \sum\left(EUT\ Impact_p + HEALTH\ Impact_{pl}\right) \quad \text{(Eq. 1)}$$

for all pollutants in all countries

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

$$HEALTH\ Impact_{pl} = Pollution_{pl} * VF_{pl\ HEALTH} \text{ for each country} \quad \text{(Eq. 3)}$$

52. The variables for the equations are as follows:

$VF_{pl\ HEALTH}$	The value factor for health for each water 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 from the Global Value Factors Database.
$VF_{p\ EUT}$	The value factor for eutrophication for each water pollutant. These values are distinct for each country where pollution occurs. The value factor should be obtained for each country from the Global Value Factors Database.
$Pollution_p$ $Pollution_{pl}$	The kilograms of water pollution released organized by the pollutant, location type, and country of release. For eutrophication impacts location is not needed.
p	Type of pollutant (e.g. phosphorus or lead).

l	Location type where water pollutant is released (freshwater, seawater, or unspecified). This consideration only applies to health impacts.

53. The water pollution impact calculation is described below.

    a. Equations 2 - 3 calculate the monetary value of impacts for each of the components of the water pollution impact pathway, eutrophication and health impacts. These are organized based on the type of pollutant, location type (only for health) and country and are presented as part of the Global Value Factors Database. The value factor for each can be multiplied by the water 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 water pollution impact can be determined by summing the two impacts for each air pollutant, location type, and country.

54. The methodology presented here is intended for use with global water pollution data organized by the country of pollution. Where highly localized valuations are required, a more locally focused approach should be applied.

55. Upstream value chain, downstream value chain, and own operations of water 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 water pollution impact regionally, nationally, or within specific value chain categories

4.2 Outcomes and impacts

56. For each impact, the approaches used to link water pollution to outcomes and impacts are described below. Additional methodological details are in Appendix B.

57. Human health impacts from toxic pollutants in water are significant and multifaceted. To estimate the societal impact of toxic pollutants on human health, specific pollutants that cause health issues are identified, such as heavy metals, pesticides, and industrial chemicals. Next, the incidence of health conditions attributable to these pollutants is estimated, including cancer, neurological disorders, and respiratory issues.

58. Outcomes and impacts related to excessive nutrients and their influence on recreation, property values, and fish stocks are combined in the monetary valuation calculation below.

4.3 Monetary valuation

59. 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.

60. Regarding human health, the Interim Water Pollution Methodology applies economic studies on the value of statistical life (VSL) to estimate the financial burden of these health conditions. Specifically, the VSL is obtained from an OECD meta-analysis, with a single value used globally such that mortality is valued the same regardless of location. The VSL used is $4,889,008 in 2023 USD. The societal cost is calculated by multiplying the incidence of health conditions by the associated medical and economic costs, thereby providing a monetary value representing the societal impact of toxic pollutants on human health.

61. The equation to determine the value factor of health impacts is shown below:

$$Value\ Factor_{c1.fw,mw,z} = Characterization\ factor_{c1,fw,z} \times DALYs_z \times DALY\ value_{c1} + Characterization\ factor_{c1,mw,z} \times DALYs_z \times DALY\ value_{c1}$$

$Characterization\ factor_{c1,fw,z}$	The number of disease incidences per kilogram of substance released to freshwater of a substance in a given country
$Characterization\ factor_{c1,mw,z}$	The number of disease incidences per kilogram of substance released to marine water of a substance in a given country
$DALYs_z$	The number of DALY associated with the critical cancer and non-cancer effects of the substance
$DALY\ value_{c1}$	The PPP adjusted value a DALY in monetary terms

62. Valuation of impacts caused by excessive nutrients including decreased recreation, property values, and fish stocks is done by a welfare-based approach to calculate generic damage values. The methodology is adapted from Ahlroth (2009)[16] who uses WTP to estimate damage values per kg of N or P. This approach makes best use of the

[16] Ahlroth, S. (2009). Developing a weighting set based on monetary damage estimates. Method and case studies. US AB : Stockholm.

somewhat limited literature on valuation of eutrophication impacts. Calculation of other countries value factors is done using Benefit Transfer.

63. Conducting primary research on WTP is expensive and time-consuming, particularly at the global scale. A more time and cost-effective alternative to primary valuation studies, widely used in policy, is benefit transfer. This involves applying estimates of WTP from existing studies to different, but sufficiently similar contexts. These values are adjusted to account for the differences in context. The breadth of applicability of benefit transfer generally rises in line with the sophistication of the adjustment technique.

64. In the context of a globally applicable methodology, there is only limited primary research on WTP values across cities and countries and those studies which do exist often use inconsistent approaches. Benefit transfer can help overcome this lack of consistent primary work by providing a single value or set of values which can be applied and adjusted consistently to different geographical and socioeconomic contexts.

65. In this methodology, Ahlroth's base values are used and adjusted to account for income. In the longer term, a more sophisticated benefit transfer function could be developed to allow adjustments for local contexts and preferences. However, insufficient primary data on the characteristics of participants in the underlying studies was available to support this approach. If the valuation approach is to be applied at a more focused geographical area it may however be possible to find or collect such data.

66. The equation to determine the value factor of eutrophication impacts is shown below:

$$Value\ Factor_{c1.fw,mw,N,P} = Eutrophication\ Potential_{c1,fw,P} \times WTP_{c1,fw,P} +$$

$$Eutrophication\ Potential_{c1,mw,N} \times WTP_{c1,mw,N} +$$

$$Eutrophication\ Potential_{c1,mw,P} \times WTP_{c1,mw,P}$$

$Eutrophication\ Potential_{c1,fw,P}$	The eutrophication potential of phosphorus released to freshwater in a given country
$Eutrophication\ Potential_{c1,mw,P}$	The eutrophication potential of phosphorus released to marine water in a given country
$Eutrophication\ Potential_{c1,mw,N}$	The eutrophication potential of Nitrogen released to marine water in a given country
$WTP_{c1,fw,P}$	PPP adjusted willingness to pay for one kg of phosphorus in freshwater in any given country
$WTP_{c1,mw,N}$	PPP adjusted willingness to pay for one kg of nitrogen in marine water in any given country

$WTP_{c1,mw,P}$	PPP adjusted willingness to pay for one kg of phosphorus in marine water in any given country

5 Future Development

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

68. Opportunities to further advance water pollution impact accounting include:

    a. Incorporating emerging pollutants: Expanding the scope of pollutants considered in the methodology to include emerging contaminants such as microplastics, and personal care products, which are increasingly recognized as significant environmental threats.

    b. Improvement on the quality and granularity of primary data where possible to avoid overreliance on secondary data/methodologies.

    c. Conducting targeted research to fill existing data gaps, particularly in areas such as groundwater contamination, thermal pollution, and ecotoxicity. This will help create a more comprehensive water pollution model and improve the accuracy of impact assessments.

    d. Research and data collection efforts to better understand the impacts of water pollution on groundwater quality. This includes developing approaches to assess the relationships between pollutant discharges, changes in groundwater quality, and human health consequences.

69. 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.

Appendix A: Glossary

Term	Definition	Source[17]
Benefit transfer	Using existing willingness to pay (WTP) estimates from one context to value similar benefits or costs in another context. This method is often used when primary valuation studies are not feasible. Also known as value transfer.	ISO 14008:2019
Transfer function	A mathematical function used for benefit transfer. While different transfer functions exist, many are a function of the average income in the original context relative to the estimated context and the income elasticity of WTP. Average income can be estimated as gross national income (GNI) per capita using purchasing power parity (PPP) exchange rates (rates of currency conversion that equalize the purchasing power of different currencies). The income elasticity of WTP is the responsiveness of WTP with respect to changes in income.	Organisation for Economic Co-operation and Development (OECD)
Water pollution	The release of substances into surface water or subsurface groundwater to the point that the substances interfere with beneficial use of the water or with the natural functioning of ecosystems.	Britannica
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	World Health Organization

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

	the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population.	
Direct in-line measurement	A method for measuring effluent discharges to water directly at the site of emission. This is considered the best practice for obtaining accurate data on water pollutants.	N/A
Eutrophication	The process by which nutrient pollutants discharged to water systems in excess result in algal blooms, hypoxic conditions, and subsequent impairment of recreational opportunities and decline in fish stocks.	National Oceanic and Atmospheric Administration (NOAA)
Eutrophication potential	Defined as the potential of a substance or process to over-fertilize the water bodies, resulting in increased growth of biomass, expressed in phosphates equivalents.[18]	Jouhara et al. (2018)
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)
Value of a statistical life (VSL)	The amount individuals would be willing to pay or to accept to experience small changes in mortality risk, which is then aggregated to estimate the monetary value of a reduction in mortality risk of 100%.	U.S. Environmental Protection Agency U.S. Department of Transportation
Primary data	Data collected by the entity or an external party specifically for the purpose in which it is used.	General Methodology 2

[18] H. Jouhara, D. Brough (2018): *The aluminium industry: A review on state-of-the-art technologies, environmental impacts and possibilities for waste heat recovery.*

Secondary data	Data originally collected and published for a different purpose. Secondary data sources include	General Methodology 2
Life cycle analysis (LCA)	A technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave.	Capitals Coalition
Limiting nutrient theory[19]	Posits that the growth of organisms, such as algae in aquatic systems, is limited by the nutrient that is in the shortest supply relative to the needs of the organisms. In freshwater systems, phosphorus is often the limiting nutrient, while in marine systems, nitrogen is frequently the limiting nutrient. This theory is used to assess the eutrophication potential of water bodies.[20]	Howarth & Marino (2006) Poikane et al. (2022)
Environmentally extended input-output (EEIO) tables	An analytical framework that uses tables to incorporate environmental data into economic input-output models, allowing for the assessment of the environmental impacts of economic activities.	UNEP

[19] Howarth, R. & Marino, R. (2006). *Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: evolving views over three decades*. Limnol. Oceanogr., 51, 364–376.

[20] Poikane, S., Kelly, M. G., Várbíró, G., Borics, G., Erős, T., Hellsten, S., Kolada, A., Lukács, B. A., Lyche Solheim, A., Pahissa López, J., Willby, N. J., Wolfram, G., & Phillips, G. (2022). *Estimating nutrient thresholds for eutrophication management: Novel insights from understudied lake types.*

Appendix B: Methodological Details

B1. The Interim Water Pollution Model incorporates the societal impacts associated with all water pollution that can be attributed to a company's operations, potentially covering multiple geographies across expansive global supply chains. The valuation approach first identifies the specific pollutants released into water bodies and quantifies their concentrations. It then estimates the environmental outcomes, such as reduced water quality and bioaccumulation of pollutants, and traces the share of water pollution for which the company is responsible. The model subsequently assesses the extent of impacts on human health, recreation, property values, fish stocks, livestock, agriculture, and other ecosystem services. Finally, the societal impacts of water pollution are quantified and converted into monetary terms, providing a comprehensive estimate of the societal costs. There are two main valuation modules within the Interim Water Pollution Methodology: 1) Toxic pollutants valuation module and 2) Nutrient valuation module.

Toxic pollutants valuation module

B2. This section covers the valuation of human health impacts from toxic pollutants emitted to water. The valuation module for toxic pollutants traces the pollutant from release to ingestion to induced health harms and ultimately values those health harms. Pollutants can enter humans via a number of pathways including direct ingestion (e.g., drinking), indirect ingestion (e.g., via bioaccumulation in fish) and direct inhalation (of evaporated pollutants that were initially emitted to water). Once ingested (or inhaled), the health harms depend on the individual pollutant and its dose. Those health harms are assigned a value using published data on what individuals would pay to avoid those harms, ultimately reaching a total societal cost of water pollution.

B3. In order to evaluate the impacts of water pollution on people, a pollutant's movement through the environment is modeled, along with humans' exposure to the pollutant, and the human health outcomes. The output of this model is the pollutant-specific 'characterization factor' which gives the number of health harms per unit of pollutant emitted. This modeling draws on a body of work known as LCA multimedia modeling. The model for the calculation of characterization factors is USEtox. [21]Among model options, it offers the largest substance coverage with more than 1,250 substances and reflects more up to date knowledge and data on effect factors than other approaches comparing multimedia models. It was specifically designed to determine the fate,

[21] Rosenbaum, R.K., Huijbregts, M.A.J., Henderson, A.D., Margni, M., McKone, T.E., van de Meent, D., Hauschild, M.Z., Shaked, S., Li, D.S., Gold, L.S., Jolliet, O., (2011). USEtox human exposure and toxicity factors for comparative assessment of toxic emissions in life cycle analysis: sensitivity to key chemical properties. The International Journal of Life Cycle Assessment 16, 710-727.

exposure and effects of toxic substances. Additionally, it has the ability to consider spatial differences with the addition of country specific parameters. USEtox has been adopted for regulatory assessments, for example the European Union's EUSES in 2004 and for persistence screening calculations as recommended by bodies such as the OECD.[22]

B4. A Bioaccumulation Factor (BAF) represents the extent to which a substance accumulates in an organism relative to its concentration in the environment. In the context of water pollution, BAF is used to estimate the concentration of pollutants in fish and other aquatic organisms. When measurements are available in the literature, these are used; otherwise, models like the Arnot and Gobas (2003) model[23] in the Estimation Programs Interface (EPI) Suite are used to estimate the BAF for non-dissociating substances.

B5. This type of model is already widely used in Life Cycle Impact Assessment (LCIA) and is recommended by the UNEP and the SETAC.[24] It was developed by a team of researchers from the Task Force on Toxic Impacts under the UNEP-SETAC Life Cycle Initiative to include the best elements of other LCA models.

B6. This methodology is built on the USEtox model in two relevant ways: increasing geographic specificity using country-level data from GLOBACK and limiting the model to only addressing emissions to water (to avoid double-counting with our other valuation methodologies e.g., air pollution). These modifications do not change any of the underlying calculations of the model.

B7. In USEtox, substances that have a potential to increase human disease have a characterization factor (CF). In LCIA, the mass of each chemical emitted is multiplied by a CF to provide the impact indicators. CFs are obtained with characterization models – in this case USEtox – which represent the mechanism of a cause–effect chain starting from an emission followed by environmental fate, human exposure, and the resulting effect on the exposed population. The CF in the USEtox model includes a fate factor (FF), an exposure factor (XF) and an effect factor (EF) (Equation 1):

$$CF = FF \times XF \times EF$$

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[22] Klasmeier, J., Matthies, M., MacLeod, M., Fenner, K., Scheringer, M., Stroebe, M., Le Gall, A.C., McKone, T., van de Meent, D., Wania, F. (2006) Application of multimedia models for screening assessment of long-range transport potential and overall persistence, Environ. Sci. Technol. 40, 53–60.

[23] Arnot, J.A., Gobas, F.A.P.C. (2003). *A generic QSAR for Assessing the Bioaccumulation Potential of Organic Chemicals in Aquatic Food-webs.* QSAR Comb. Sci. 22: 337-345.

[24] Pennington, D.W., Margni, M., Amman, C., Jolliet, O., (2005). Spatial versus non-spatial multimedia fate and exposure modeling: insights for Western Europe. Environ. Sci. Technol. 39 (4), 1119–1128.

a) The fate factor describes the amount of contaminant in air, water and soil (termed environmental compartments) available for eventual intake by humans. It is calculated based on the substance's mobility and persistence in the environment. It assesses the residence time of a substance in water, considering processes like adsorption, sedimentation, volatilization, degradation, and advective transport.

b) The exposure factor describes the contaminant intake of the human population due to the mass of substance in the environment considering direct ingestion, direct inhalation, and indirect ingestion through bio-concentration in animal tissues. Essentially it is a substance's likelihood to interact with a receptor; it calculates the number of people exposed and the extent of their exposure. The scope of this methodology is ingestion (direct and indirect) and direct inhalation, as dermal contact is currently not covered by the USEtox model.

c) The effect factor describes determines the quantitative relationship between the dose of a substance received and the incidence of adverse health effects in the exposed population. It reflects the change in lifetime disease probability due to changes in lifetime intake of a pollutant. It is based on a linear dose response function. Although there are a variety of approaches to modeling dose-response, the linear model has been deemed most appropriate for the Interim Methodology.

Assumptions	**Comment on purpose and reasonableness**
Simplified fate and exposure modeling using the USEtox parameters at a country level	Geophysical data are defined at a country level, but are able to be defined locally where exact emission source location is known. It is therefore a necessity to simplify geophysical conditions. USEtox was developed by the Task Force on Toxic Impacts under the UNEP-SETAC Life Cycle Initiative to include the best elements of available LCA multi-media models.
Steady state conditions when calculating substance fate	This modeling technique is well established in the literature.
A linear dose response function is assumed when determining ED50[25]	A linear function assumes that emission concentrations are already above any damage threshold, such that any addition of pollution in the environment causes an impact. Determining whether

[25] Effective Dose 50 (ED50): A standard measure used in toxicology to represent the dose of a substance that produces a therapeutic or toxic effect in 50% of the population.

	pollutants are below any damage threshold requires data on ambient concentration and biogenic emissions data which are not globally available. Linear functions are therefore the standard in academic and government analysis.

B8. To value the health harms and reach the societal impact of water pollution, the severity of these harms using Disability-Adjusted Life Years (DALYs is approximated). Monetary values are then applied to these DALY totals based on willingness to pay (WTP) estimates to provide comprehensiveness in the valuation. DALYs, commonly used by health economists and policymakers, help compare the cost-effectiveness of investments but typically do not value the welfare loss associated with a DALY. Lvovsky[26] developed a methodology to derive the value of a DALY from the Value of a Statistical Life (VSL) and the number of DALYs lost, which has been applied in various policy contexts, including the EU's REACH policy. Due to limited data, direct estimates of the value of negative health cases via WTP are not feasible, making DALYs a necessary interim step.

Nutrient valuation module

B9. This section covers the valuation of societal costs of emitting excess nutrients to water. The valuation module for nutrients estimates the eutrophication potential of nutrients in fresh and marine water and then estimates the value based on published data on what individuals would pay to avoid those harms.

B10. The eutrophication potential of excessive nutrients released into the watercourse is calculated. Only P for emissions to freshwater, and both N and P for marine water, due to the limiting nutrient theory, are considered. Limiting nutrient theory can be summarized as follows:

a) In different environments algal growth is limited by different nutrients. If more of the limiting nutrient is introduced into the system, this will promote an increase in growth. However, an introduction of other, nonlimiting, nutrients will have no effect on growth.

b) In freshwater, P is often considered the limiting nutrient. When salinity increases, N contributions to eutrophication increase. In temporal zones N is probably the major cause of eutrophication in most coastal systems; however, P

[26] Lvovsky, K., Hughes, G., Maddisonl, D., Ostro, B., Pearce, D. (2000). Environmental Costs of Fossil Fuels. World Bank Environment Department Papers No. 78, Pollution Management Series.

can limit primary production in other systems. Therefore, both N and P are considered to contribute to eutrophication in marine waters.

c) In application to impact assessment, most models adopt these general rules, acknowledging that it is a simplification as other nutrients can be limiting in specific conditions.

B11. For both marine water and freshwater, eutrophication potential of P and N is modelled using the respective LC Impact Characterization Factors. Leading approaches wherever possible including those of the ISO handbook on Life Cycle Assessment.

B12. The characterization factor calculated by the LC Impact, is a product of FF, EF and XF, and includes the impacts in the area of protection 'Ecosystem quality' caused by the emission of phosphorus (P) into the freshwater and into the soil compartment. A higher characterization factor means a more severe impact on aquatic life.[27] For marine water, the LC Impact marine eutrophication model adopts a spatially differentiated approach, using the Large Marine Ecosystems (LME) biogeographical classification system, which divides coastal regions into 66 spatial units. This can then be used to determine the spatial differentiation of eutrophication potential of both P and N.

B13. Excessive nutrients lead to various negative consequences, such as reduced recreational opportunities, lower property values, and decreased fish populations. To estimate the general damage values associated with these impacts, a welfare-based approach is adopted. This approach is derived from Ahlroth (2009), who employs Willingness to Pay (WTP) to determine damage values per kilogram of nitrogen (N) or phosphorus (P). This method effectively leverages the limited available literature on the valuation of eutrophication impacts. Benefit Transfer is then used to apply these published values to other countries.

B14. *Valuing eutrophication in freshwater*: Ahlroth presents an approach to use WTP estimates for reduced eutrophication impacts to calculate a generic damage value per kg of P released to freshwater in Sweden. Studies in other parts of the world are currently limited. The benefit transfer approach presented below is based on Ahlroth's values but could be applied to other source data where available. In applying values from a benefit transfer approach, such as this, it is important to consider the applicability of these values to other areas.

B15. Ahlroth analyzed existing valuation studies that estimated the value of improving water quality in a lake or watercourse. The author constructed a generic damage value per kg of P in Sweden, using a structural benefit transfer of eight studies to calculate total WTP

[27] LC Impact (2021): *Freshwater eutrophication.*

and annual deposition amount. The underlying studies were similar in design and valued a quality change. Respondents were presented with different water quality scenarios, described using a water quality ladder. The ladder presented incremental improvements in water quality based on the water's suitability for drinking, bathing, irrigation, recreational fishing and boating.[28] Respondents provided their WTP to move between the scenarios. An average WTP per unit of emission was calculated based on the reduction in nutrient loading necessary to move between water quality scenarios.

B16. Ahlroth assumes a constant marginal WTP. To transfer this value from Sweden to other countries, the WTP values is adjusted by PPP.[29]

B17. *Valuing eutrophication in marine water.* The approach to valuing marine water nutrients is similar to that for freshwater nutrients. For coastal areas, Ahlroth analyzed existing valuation studies that estimated the value of improving water quality in marine water. As per the approach taken for freshwater, Ahlroth calculates a per kg WTP value for phosphorus and nitrogen, using a structural benefit transfer method.

B18. To transfer values from Sweden to other countries, WTP values are adjusted by PPP. Ahlroth constructed generic damage values for phosphorus, nitrogen, ammonia, and nitrogen oxide (NOx). The scope of the Interim Water Pollution Methodology does not cover emissions to air that lead to eutrophication; therefore, only the generic damage values for phosphorus and nitrogen were modeled. However, the aerial eutrophication emissions are likely to be trivial, based on general research on the amount of eutrophying nutrients emitted to air versus water.

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[28] Norwegian State Pollution Control Agency, 1989. Vannkvalitetskriterier for ferskvann. (Water quality criteria for freshwater). Holtan H., Ed. SFT-rapport TA-630.

[29] In the future, transfer functions that consider more local data e.g. socio-economic characteristics, physical environmental conditions, cultural factors could be considered.

Appendix C: Value Accountability Framework – Value Factors

This Appendix presents the Water 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 Water 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: The impact in dollars per kilogram of pollutant, into freshwater, marine water, or unspecified, per country.</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.</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 organic, inorganic and nutrient pollutants emitted to freshwater and marine water within the entities’ full value chain.

2. The value factor captures (1) impacts to human health from exposure to water pollution, and (2) impacts on environmental quality from eutrophication from nitrogen and phosphorus. This covers emission of water pollutants to both seawater and freshwater.

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 MONETARY VALUE</th></tr>
<tr><td>Approach and specificity</td><td>5. The potential impacts of effluents on human health are modeled based on the</td><td>8. The severity of health impacts are assessed using Disability Adjusted Life Years (DALYs) and valued</td></tr>
</table>

	chemical fate as the pollutant travels through different media (water, soil, air, food products), and the likelihood of human exposure. 6. Dose-response functions describe the likelihood of different health impacts occurring given a specified level of exposure. Chemical and impact specific functions estimate health outcomes for populations exposed to pollutants. 7. The eutrophication impacts are determined using the eutrophication potential of Phosphorus and Nitrogen in Freshwater and Marine Water respectively	using the Organization for Economic Co-operation and Development (OECD) methodology for valuing changes in health and life. 9. To determine the cost of eutrophication to society, values based on estimations of WTP are used. 10. These eutrophication damage values are based on structural benefit transfer from contingent valuation studies.
Data inputs	11. Country-specific data is sourced from the World Bank, GLOBACK Database (University of Leiden), and LC Impact. Substance-specific data is sourced from USEtox. 12. For further data sets see Appendix B: Methodological Details along with the primary literature sources cited in each.	
VIEWS OF AFFECTED STAKEHOLDERS		
Representation of stakeholders	13. 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.	
ETHICAL DECISIONS IN ESTIMATING SOCIETAL IMPACT		
Equity weightings and income adjustments	14. The health impacts of water pollution use a global DALY value to ensure equity in consideration of impacts regardless of their location.	
Accounting for future impacts	15. N/A	

Other ethical considerations	16. N/A
	SENSITIVITY
Sensitivity to key variables	17. Sensitivity analysis was carried out for a number of variables (Access to improved water, Dose-response coefficients, DALYs per disease type, VSL/Value of a DALY, Eutrophication characterization factors, societal cost per tonne of phosphorus and nitrogen in freshwater and marine water|), for 3 countries (United States, China and Nigeria). For full results see Table 2.

Table 3: Sensitivity analysis

		Arsenic			Mercury		
Variable (Health Impacts)	**Flex**	**US (% change)**	**China (%change)**	**Nigeria(% change)**	**US (% change)**	**China (%change)**	**Nigeria(% change)**
Access to improved water	10%	0%	-0.16%	-0.631%	0%	-0.013%	-0.132%
Dose-response coefficients	10%	-10%	-10%	-10%	-10%	-10%	-10%
DALYs per disease type	10%	10%	10%	10%	10%	10%	10%
Value of a DALY	10%	10%	10%	10%	10%	10%	10%
Value of a DALY (Income Adjustment)	Adjustment of the value of changes in health outcomes for national income (vs base case of no adjustment)	9%	23%	21%	16%	23%	21%

		Phosphorus			Nitrogen		

Variable (Health Impacts)	Flex	US (% change)	China (%change)	Nigeria(% change)	US (% change)	China (%change)	Nigeria(% change)
Eutrophication Characterization Factors	10%	10%	10%	10%	10%	10%	10%
Societal cost per metric ton of phosphorus in freshwater	10%	10%	10%	10%	10%	10%	10%
Societal cost per metric ton of nitrate in marine water	10%	10%	10%	10%	10%	10%	10%

Appendix D: Data Sources in the Interim Water Pollution Methodology

Data	Source[30]	Year
Advanced economy	IMF WEO	2023
Value of a DALY	OECD	2023
Birth rate (per 1000)	World Bank	N/A
National improved water access	World Bank	2022
Coastal population	SEDAC	2010
Continental scale area land	GLOBACK	2010
Continental scale area sea	GLOBACK	2010
Continental scale areafrac freshwater	GLOBACK	2010
Continental scale areafrac nat soil	GLOBACK	2010
Continental scale areafrac agr soil	GLOBACK	2010
Continental scale areafrac other soil	GLOBACK	2010
Continental scale temp	GLOBACK	2010
Continental scale surface wind speed	GLOBACK	2010
Continental scale wind speed over mixing height	GLOBACK	2010
Continental scale rain rate	GLOBACK	2010

[30] Sources are hyperlinked for your reference.

Continental scale depth fresh water	GLOBACK	2010
Continental scale fraction fresh water discharge	USEtox2.13	2023
Continental scale fraction run off	USEtox2.13	2023
Continental scale fraction infiltration	USEtox2.13	2023
Continental scale soil erosion	USEtox2.13	2023
Continental scale irrigation	GLOBACK	2010
Global scale area land	USEtox2.13	2023
Global scale area sea	USEtox2.13	2023
Global scale areafrac freshwater	USEtox2.13	2023
Global scale areafrac nat soil	USEtox2.13	2023
Global scale areafrac agr soil	USEtox2.13	2023
Global scale areafrac other soil	USEtox2.13	2023
Global scale temp	USEtox2.13	2023
Global scale surface wind speed	USEtox2.13	2023
Global scale rain rate	USEtox2.13	2023
Global scale depth fresh water	USEtox2.13	2023
Global scale fraction fresh water discharge	USEtox2.13	2023
Global scale fraction run off	USEtox2.13	2023
Global scale fraction infiltration	USEtox2.13	2023

Global scale soil erosion	USEtox2.13	2023
Global scale irrigation	USEtox2.13	2023
Urban scale area land	USEtox2.13	2023
Urban scale areafrac unpaved area	USEtox2.13	2023
Urban scale areafrac paved area	USEtox2.13	2023
Exposure human breathing rate	GLOBACK	2010
Exposure water ingestion rate	GLOBACK	2010
Above-ground produce world	USEtox2.13	2023
Above-ground produce continent	GLOBACK	2010
Below-ground produce world	USEtox2.13	2023
Below-ground produce continent	GLOBACK	2010
Meat intake world	USEtox2.13	2023
Meat intake continent	GLOBACK	2010
Dairy products intake world	USEtox2.13	2023
Dairy products intake continent	GLOBACK	2010
Fish freshwater world	USEtox2.13	2023
Fish freshwater continent	GLOBACK	2010
Fish coastal marine water world	USEtox2.13	2023
Fish coastal marine water continent	GLOBACK	2010

World population	World Bank	N/A
Helme's fate factors	Spatially explicit fate factors of phosphorous emissions to freshwater at the global scale	2012
CF for P emissions to freshwater	LC Impact FW Eutrophication	2019
CF for direct N emission to marine system	LC Impact MW Eutrophication	2019

Appendix E: List of Water Pollutants

Impact pathway	Pollutant
Eutrophication	Nitrogen
	Phosphorus
Human health	Antimony – Sb(III) and Sb(V)
	Arsenic – As (III) and As(V)
	Cadmium – Cd (II)
	Chromium – Cr(III) and Cr(VI)
	Copper – Cu(II)
	Lead – Pb(II)
	Mercury – Hg(II)
	Nickel – Ni(II)
	PAHs
	Zinc – Zn(II)
	Silver – Ag(I)
	Barium – Ba(II)
	Beryllium – Be(II)
	Cobalt – Co(II)
	Molybdenum – Mo(VI)
	Selenium – Se(IV)

	Thallium – Tl(I)
	Vanadium – V(V)
	1,2-dichlorobenzene
	1,2-dichloroethane
	1,2-DIMETHYL-5-NITRO-1H-IMIDAZOLE
	1,3-Dichloropropene
	1,4-dichlorobenzene
	2-(2,4-dichlorophenoxy)acetic acid
	2,4,6-trichlorophenol
	2-CHLOROPHENOL
	3-Methylcholanthrene
	4-CHLOROANILINE
	7,12-Dimethylbenz(a)anthracene
	Acenapthene
	ACEPHATE
	ACETAMIDE, N-(4-HYDROXYPHENYL)
	Albuterol
	Aldicarb
	Aniline
	Anthracene

	ANTIPYRINE
	Atrazine
	Benzene
	Benzidine
	benzo[a]pyrene
	Bezafibrate
	butyl benzyl phthalate
	Carbamazepine
	Chlorobenzene
	Chloropyrifos
	Chlorothalonil
	CYANAZINE
	CYPERMETHRIN
	DEF
	di-(2-ethylhexyl)-phthalate (DEHP)
	Diazinon
	Dibenz(a,h)anthracene
	Dicamba
	dichloromethane/methylenechloride (CH2Cl2)
	Diclofenac

	Dicrotophos
	Ethephon
	fluoranthene
	Fluorene
	Fluvastatin
	FUROSEMIDE
	Gemfibrozil
	GLUFOSINATE-AMMONIUM
	Glyphosate
	INDOMETHACIN
	Iopromide
	Malathion
	Mancozeb
	Methyl Bromide
	Metolachlor
	Metoprolol
	METRONIDAZOLE
	Naled
	NALIDIXIC ACID
	Naphthalene

	OXOLINIC ACID
	Paraquat
	Parathion-methyl
	Pendimethalin
	pentachlorophenol
	Phorate
	Propanil
	Pyrene
	Pyrene, 1-nitro-
	Sulfamethoxazole
	Terbutaline
	tetrachloroethylene
	THIABENDAZOLE
	TRI-2-CHLOROETHYL PHOSPHATE
	Trichloroethylene
	Trifluralin
	TRIMETHOPRIM
	Tris (2,3-dibromopropyl) phosphate
	trrichloromethane/chloroform (CHCl3)
	Warfarin

	Analgesics
	anesthetics & NSAIDs
	Anthelminthics
	Antibiotics
	Anticoagulants
	Antihyperlipidemic agents
	Beta-agonists
	Beta-blockers
	Contrast agents
	Diuretics
	Psychiatric drugs
	Pesticides

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