Harvard Business School
Impact-Weighted Accounts Project

Practitioner Guide to Calculating Corporate Environmental Impact

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The monetary valuation of environmental impacts applied in this methodology is derived from the Environmental Priorities Strategies framework, a product design tool developed collaboratively by the Swedish Life Cycle Center and the Swedish Environmental Research Institute.

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Abbreviations

CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide-equivalent
E P&L	Environmental Profit and Loss
EEIO	Environmentally Extended Input-output Modelling
EPA	Environmental Protection Agency
EPS	Environmental Priorities Strategies
FAO	United Nations Food and Agriculture Organization
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HBS	Harvard Business School
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IWA	Impact-Weighted Accounts Initiative
kWh	Kilowatt Hour
LCA	Life Cycle Assessment
NO_x	Mono-nitrogen Oxides: NO and NO_2
O_3	Ozone
OECD	Organization for Economic Co-operation and Development
$PM_{10.}$	Coarse Particulate Matter (diameter under 10μm)
$PM_{2.5}$	Fine Particulate Matter (diameter under 2.5μm)
SCC	Societal Cost of Carbon
SO_x	Sulphur Oxides
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound

Introduction

As the sustainable use of natural capital becomes an increasingly central concern in the construction of an enduring business strategy, corporates and business manages are actively seeking management of capital use and impact through quantification of environmental risk exposure. A path to market optimization of natural capital may be taken by integrating environmental externalities into the assessment of corporate performance. The Impact-Weighted Accounts (IWA) methodology for Corporate Environmental Impact developed at Harvard Business School (HBS) seeks to help market participants internalize natural capital pricing by taking a practical approach towards monetizing environmental externalities through the integrated accounting of corporate operations.

Natural Capital Accounting

The increased pressure of environmental degradation, decreased availability of freshwater supplies, growing population, and decreasing food production capacity pose significant threats to economic growth and human prosperity. Given the depletion of natural capital alongside regulatory pressures, market analysts have become increasingly focused on understanding the degree to which corporates are well positioned to respond to these challenges and investors seek to allocate capital in a manner that will minimize these negative externalities. This guide is designed to help both corporates and investors estimate, in monetary terms, a firm's environmental externalities to gain insight into how well firms are positioned to respond to environmental challenges.

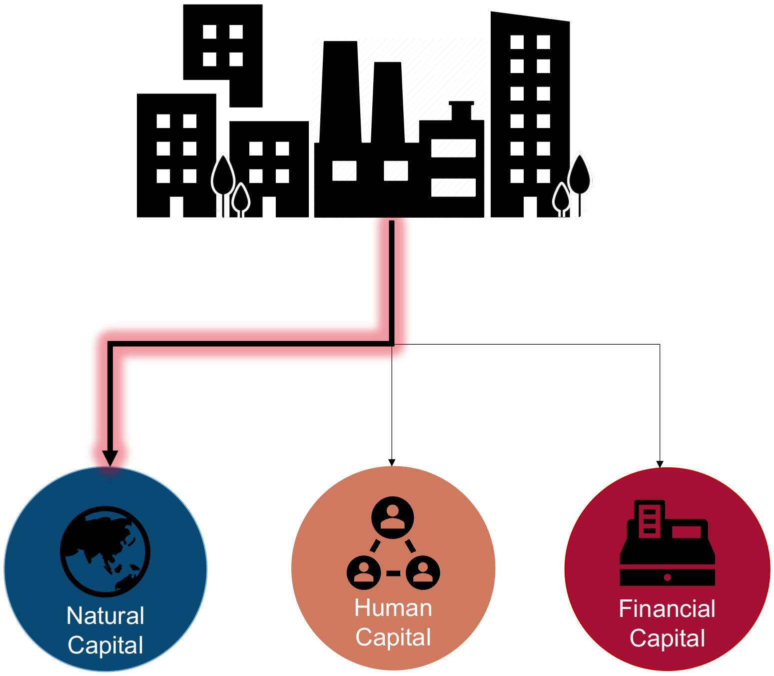
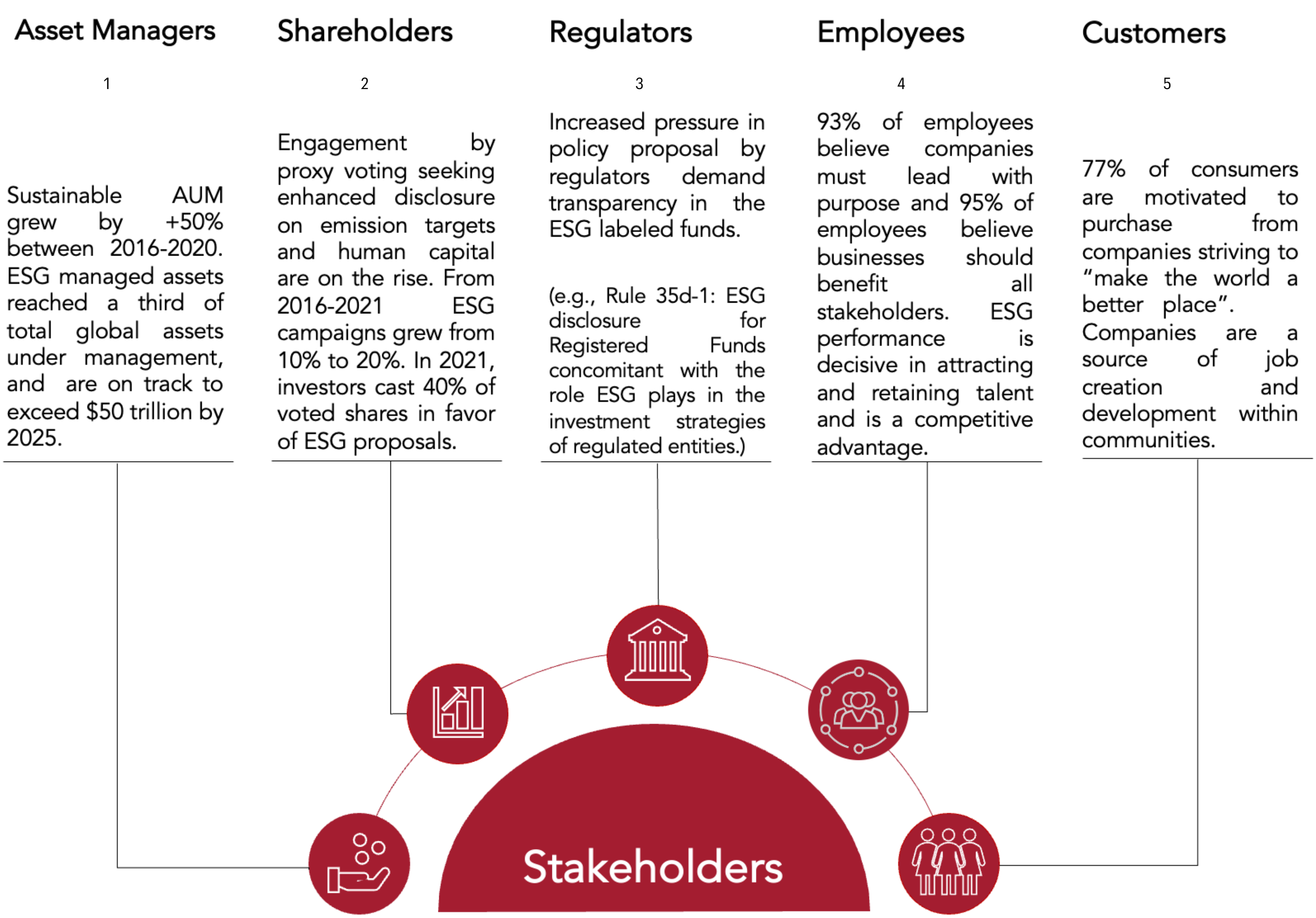


Figure 1 | Natural, Human and Financial Capital Accounting

The current market environment requires a broader assessment of corporate performance along more comprehensive metrics. Correspondingly, corporate managers are increasingly being driven towards broader value orientations in the management of a firm's human, natural and financial capital by an increasingly diverse range of stakeholders. Externalities may become liabilities in the context of expanding regulation and inadequate accounting of essential resources such as a consistent workforce, dependable customer sales, and committed investors. As a necessary measure, business leaders must expand the management of capital beyond financial capital to craft an enduring business strategy. Enduring business value is achieved through transparency and alignment between the ideals of stakeholder capitalism and shareholder primacy.



Asset Managers [1]

Sustainable AUM grew by +50% between 2016-2020. ESG managed assets reached a third of total global assets under management, and are on track to exceed $50 trillion by 2025.

Shareholders [2]

Engagement by proxy voting seeking enhanced disclosure on emission targets and human capital are on the rise. From 2016-2021 ESG campaigns grew from 10% to 20%. In 2021, investors cast 40% of voted shares in favor of ESG proposals.

Regulators [3]

Increased pressure in policy proposal by regulators demand transparency in the ESG labeled funds.

(e.g., Rule 35d-1: ESG disclosure for Registered Funds concomitant with the role ESG plays in the investment strategies of regulated entities.)

Employees [4]

93% of employees believe companies must lead with purpose and 95% of employees believe businesses should benefit all stakeholders. ESG performance is decisive in attracting and retaining talent and is a competitive advantage.

Customers [5]

77% of consumers are motivated to purchase from companies striving to "make the world a better place". Companies are a source of job creation and development within communities.

Figure 2 | Corporate Stakeholder

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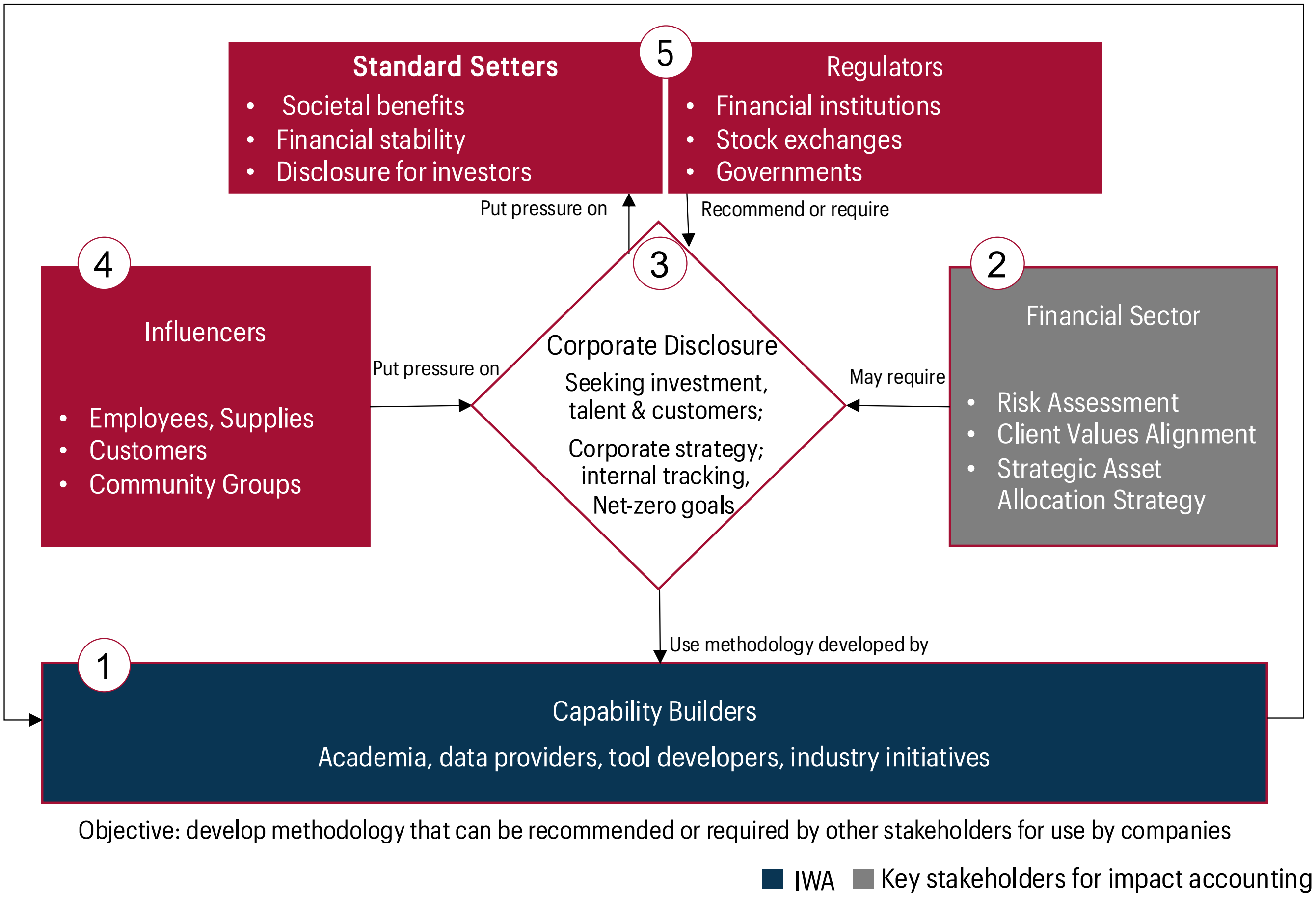
[1] Statista (2022). Value of sustainable assets under management (AUM)...from 2016 to 2020.
[2] Harvard Law School Forum on Corporate Governance (2021). Shareholder Activism and ESG.
[3] SEC (2022). Enhanced Disclosures by Certain Investment Advisers...about [ESG] Investment Practices.
[4] Harvard Business School Online (2021). Business Insights: Corporate Social Responsibility Statistics.
[5] Harvard Business School Online (2021). Business Insights: Corporate Social Responsibility Statistics.

The difference between stakeholder capitalism and shareholder primacy is time horizon; convergence is observed between the two over a 20-year time horizon [6]. Given this, fiduciary duty is a long-term commitment with aligned values. Accordingly, fiduciary duty must be based on a business strategy which places the long-term corporate success ahead of short-term profits through the incorporation of financially material externalities.

The purpose of this guide is to demonstrate how to derive monetary impact valuation related to impacts on natural capital by translating inputs, activities, and emissions into financial These impacts are translated into traditional financial measures that can be applied to capital allocation decisions. Sustainability impacts can be integrated alongside traditional financial metrics in corporate decision-making with the goal of enhancing transparency around measurement and enabling a shift from traditional risk-return assessments to risk-return-impact assessments.

Stakeholders



Objective: develop methodology that can be recommended or required by other stakeholders for use by companies

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[6] Eccles, R.G., Ioannou, I. and Serafeim, G., 2014. The impact of corporate sustainability on organizational processes and performance. Management science, 60(11), pp.2835-2857.

Corporate Environmental Impact

Economic activity requires energy and resource inputs to drive exchange within all business sectors. All corporate resource inputs produce outcome emissions, consumption, and waste as a function of corporate resource consumption. Corporate resource consumption and waste result in environmental outcomes that may produce damage to human health, the natural and built environment. Environmental outcomes result in societal damage costs in the form of resource degradation, decreased production capacities, and losses to economic productivity. Impact valuation seeks to understand how to appropriately place an economic value upon the social, environmental, and managerial contributions, as well as the cost, of corporates to society as a function of capital consumption. IWA's Corporate Environmental Impact methodology provides a framework for quantitatively assessing the economic cost in monetary units of corporate capital resource consumption.[7]

Primary components of the IWA Corporate Environmental Impact

1. Air Emissions + Air Emissions to Water
2. Abiotic Resource Use
3. Water Consumption

A note on corporate land use with particular attention to biodiversity loss:
Although corporate land use is an activity which has significant impacts on the natural environment with consequent environmental impacts, particularly on accelerating biodiversity loss, the IWA Corporate Environmental Impact methodology limits the boundaries of measurement to the components listed above. The current version of the methodology does not include corporate land use as an impact valuation metric. This exclusion results in an underestimation of corporate environmental impact on critical safeguard subjects such as biodiversity as well as other land-occupation based impacts. As corporate disclosure improves with asset and activity-level location data sets, the IWA methodology will seek to expand measurement to equally weight corporate impact across data-accessible metrics.

For the methodology to be scalable and cost effective, emissions and resources measured are those determined to be financially material to business as deemed by SASB [8].

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[7] Steen, B. (2019). Monetary Valuation of Environmental Impacts: Models and Data. Milton, CRC Press LLC.
[8] Sustainability Accounting Standards Board (SASB). Materiality Map.

Air Emissions

Please see appendix for more information.

Financially Material Greenhouse Gas Emissions

Greenhouse Gases

Greenhouse gases such as CO_2, CH_4, N_2O, and ozone, O_3, contribute to climate change by driving an increase in average ambient temperature on a global scale.[9] Their impact is attributed using global parameters as well as global costs per kg of emission.

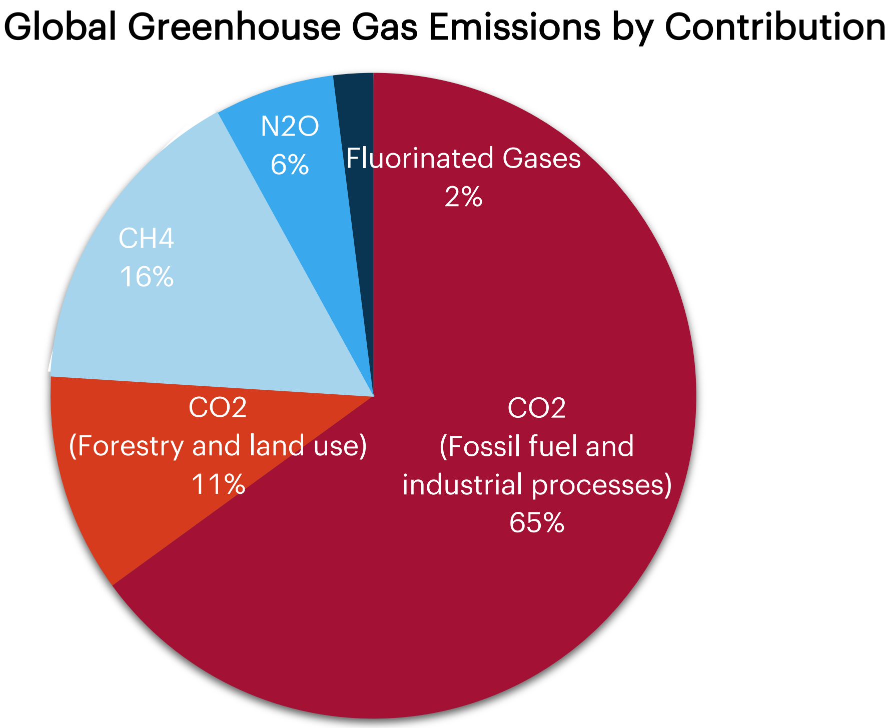

Figure 3 | Global Greenhouse Gas Emissions[10]

CO_2 | (GWP 100: 1)

Carbon dioxide emissions are the primary driver of climate change and contribute in the largest proportion to global greenhouse gases[11].

Air Pollutant Emissions

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[9] EPA (2022). Global Greenhouse Gas Emissions Data.

[10] IPCC (2014). Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[11] EPA (2022). Global Greenhouse Gas Emissions Data.

NO_x | (GWP 100: - 95 ± 31)

Nitrogen Oxides are mono- and di-nitrogen oxides which are toxic and highly reactive oxidizing agents produced when hydrocarbon fuel is burned.

SO_x | (GWP 100: - 40)

Sulphur Oxides are primarily Sulphur dioxide with some Sulphur trioxide, which are toxic and highly reactive oxidizing agents produced when hydrocarbon or high Sulphur content fuel is burned at high temperatures.

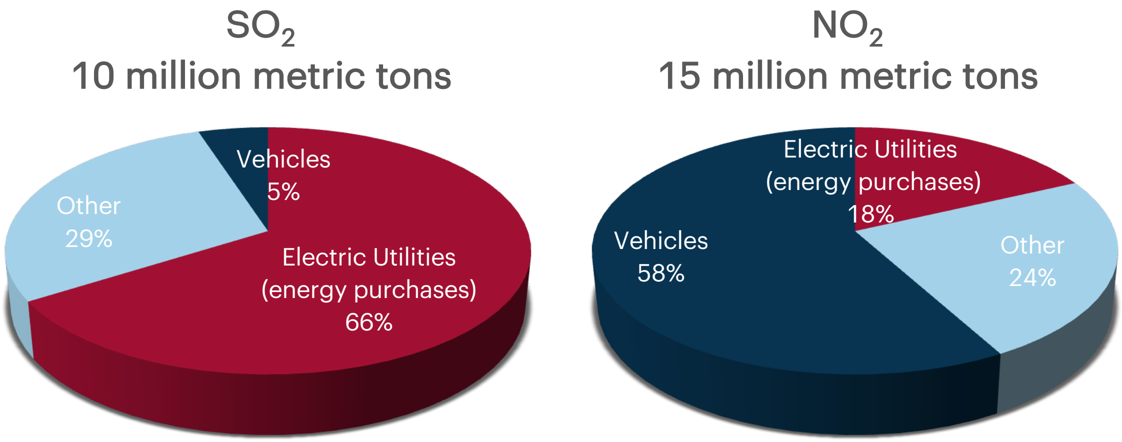

Figure 4 | Air Pollutant Emissions [12]

$PM_{2.5}$

Particulate matter of diameter 2.5 micrometers and smaller are fine inhalable particles produced directly through sources such as construction sites, smokestacks, or fires.

VOCs

Volatile organic compounds are gaseous industrial chemicals and solvents produced in the manufacturing of industrial and household products such as paints, adhesives, pharmaceuticals, cleaning supplies, cosmetics, and refrigerants.

NMVOC

Non-methane volatile organic compounds are identical to VOCs with the exclusion of methane, which is non-toxic in terms of air pollution. NMVOC is an O_3 precursor and produced through transportation, combustion activities, solvent use, and production processes.

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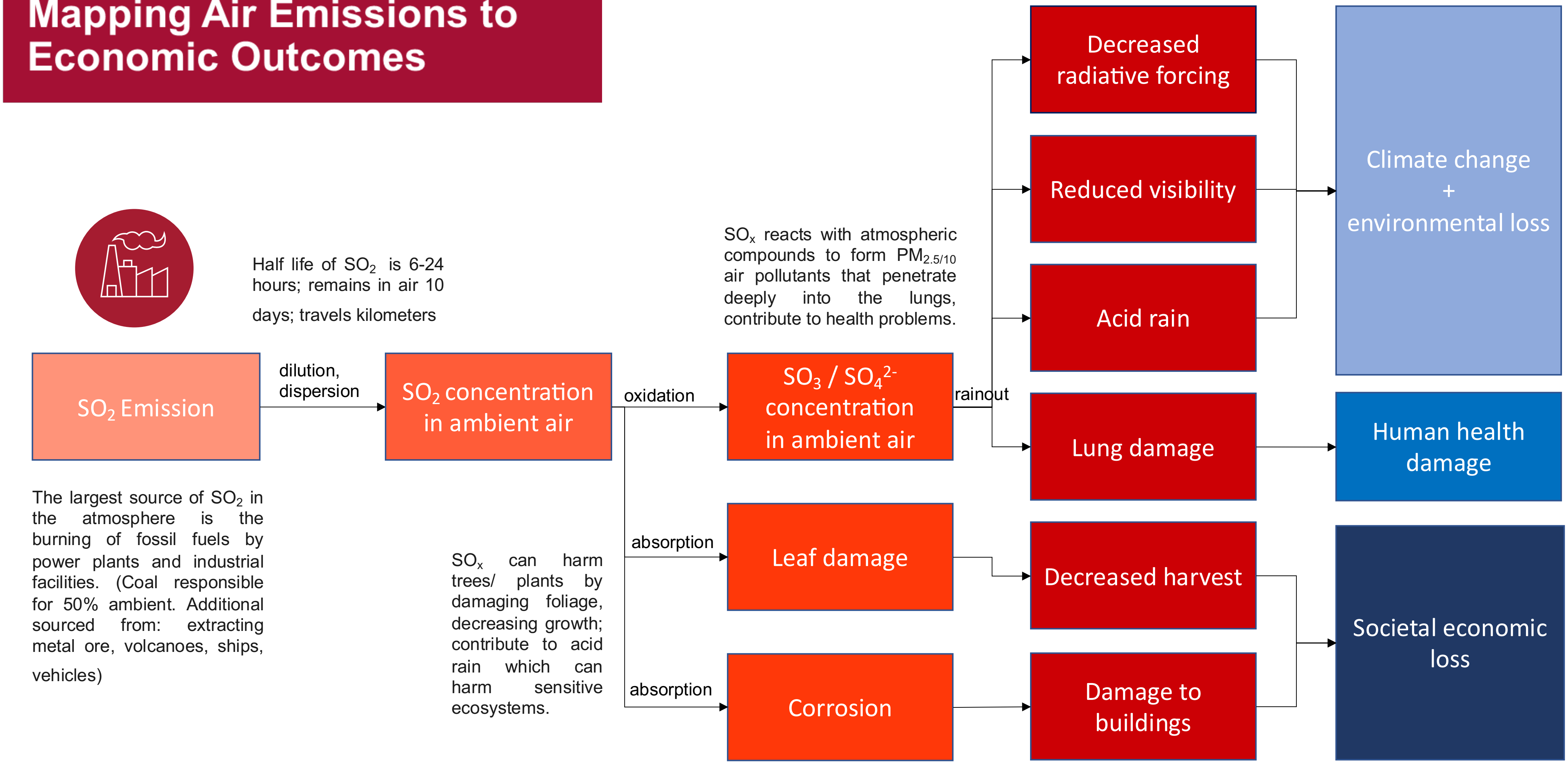
[12] EPA (2020). National Emissions Inventory (NEI).

Mapping Air Emissions to Economic Outcomes



Half life of SO_2 is 6-24 hours; remains in air 10 days; travels kilometers

SO_x reacts with atmospheric compounds to form $PM_{2.5/10}$ air pollutants that penetrate deeply into the lungs, contribute to health problems.

SO_2 Emission

dilution, dispersion

SO_2 concentration in ambient air

oxidation

SO_3 / SO_4^{2-} concentration in ambient air

rainout

Decreased radiative forcing

Reduced visibility

Acid rain

Lung damage

Climate change + environmental loss

Human health damage

absorption

Leaf damage

absorption

Corrosion

Decreased harvest

Damage to buildings

Societal economic loss

The largest source of SO_2 in the atmosphere is the burning of fossil fuels by power plants and industrial facilities. (Coal responsible for 50% ambient. Additional sourced from: extracting metal ore, volcanoes, ships, vehicles)

SO_x can harm trees/ plants by damaging foliage, decreasing growth; contribute to acid rain which can harm sensitive ecosystems.

Figure 5 | Emissions to Impact Pathways: Source and impact mechanisms for SO_2 emissions.[13]

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[13] Adapted from Steen, B. (2019). Monetary Valuation of Environmental Impacts: Models and Data. Milton, CRC Press LLC.

Water Consumption

Financially material water use

The increasing scarcity of water for consumption across a range of human and economic activities pose a significant environmental and financial liability for corporate operations. [14] Access to freshwater poses a significant financially material risk for both water-intensive industries and industries for whom water is deemed non-material, alike. Quantification and mitigation of water scarcity risk requires a granular understanding of impact at the source of corporate operations. IWA's Corporate Water Cost methodology provides tiered levels of spatial resolution in measuring localized water costs dependent on data availability. As the integration of the financial valuation of natural capital moves forward and corporate disclosure advances, users with appropriate data may apply the localization level that suits their assessment needs.

Abiotic Resources

Financially material abiotic resources

The use of abiotic resources is highly industry dependent, and it is concentrated in industries where resource extraction is a primary component of the business model, such as the manufacture of iron, steel, mining and sea and costal water transport. A decrease of a stock of abiotic resources are valued through the cost for its restoration with a sustainable alternative. [7]

Top 10 Sub-Industries by Consumption of Abiotic Resources [15]

1 Manufacture of basic iron, steel and ferro-alloys
2 Sea and costal water transport
3 Copper production
4 Mining of coal and lignite
5 Manufacture of fabricated metal products
6 Cultivation of cereal grains
7 Production of electricity by petroleum, extraction of petroleum, refining
8 Quarrying of sand and clay
9 Chemicals and mining of chemical and fertilizer minerals
10 Manufacture of electrical machinery

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[14] Bloomberg L.P., "Tesla's German Factory Will Exhaust the Area's Water Supply" Bloomberg 2022.

[15] Stadler, Konstantin, et al. "EXIOBASE 3: Developing a time series of detailed environmentally extended multi-regional input-output tables." Journal of Industrial Ecology 22.3 (2018): 502-515.

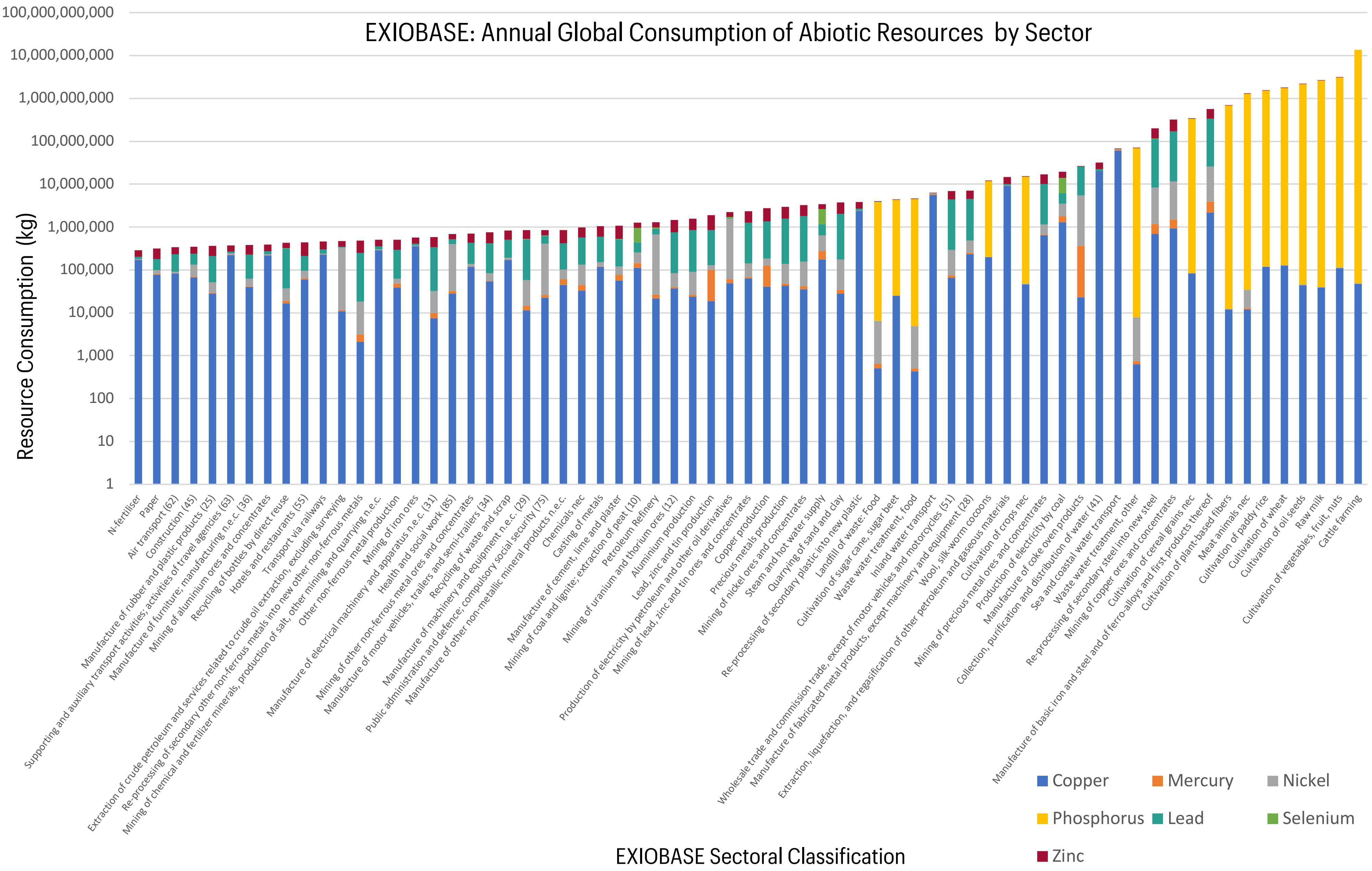

Figure 6 | Annual Global Consumption of Abiotic Resources

Biodiversity

Biodiversity is almost impossible to value and difficult to measure.[7] The collapse of ecosystems due to biodiversity loss would be catastrophic, however, there are no quantitative assessments that have managed to determine a monetary value on biodiversity itself. Due to this, the proportional share of total Corporate Environmental Impact cost attributed to biodiversity decrease is small. This relative size does not reflect a small impact but rather it reflects the lack of scientific biodiversity monetary valuations. The only monetary measure that is estimated is the conservation and preservation cost of declining biodiversity. This valuation method is applied in the IWA Corporate Environmental Impact methodology. The International Union for Conservation of Nature (IUCN) database on red-listed species threated by human activities is used to estimate and allocate the total monetary value of decreased biodiversity. The proportion of threatened species due to human activities are used as a proxy to estimate decreased biodiversity and allocates monetary value by human activity.[7] **Please note**, although biodiversity loss due to corporate land use is a significant contributor to decreased biodiversity, the IWA methodology limits the analysis to corporate emissions and does not include corporate land use as a metric by which to measure biodiversity loss.

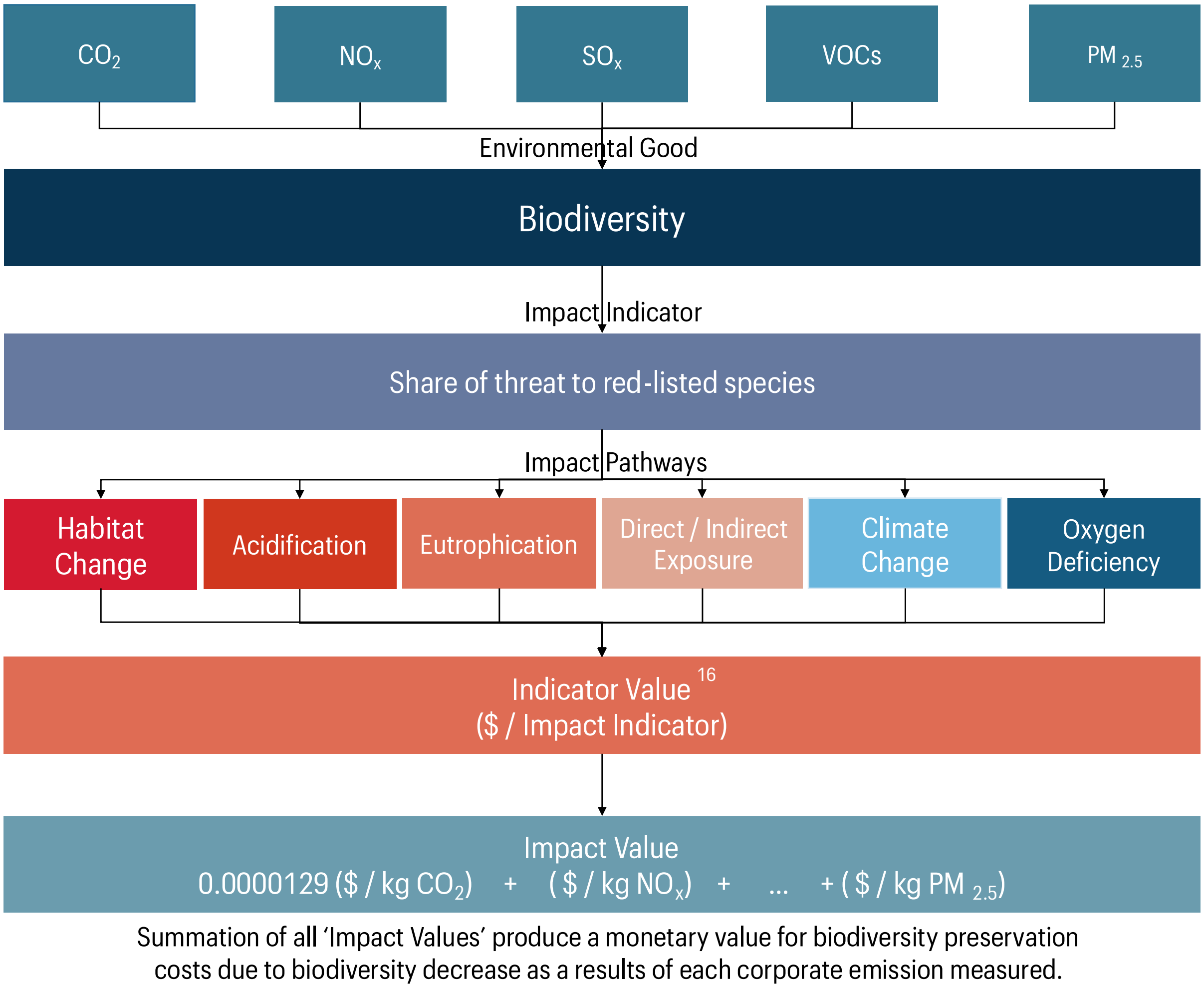

Figure 7 | Monetary Value of Declining Biodiversity

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[16] McCarthy, Donal P., et al. "Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs." Science 338.6109 (2012): 946-949. * Estimated total value of biodiversity is 76.1 billion $/year.

Environmental Goods

Monetary valuation of environmental impacts begins with understanding resource consumption within the context of basic needs and need satisfiers. “Environmental goods” are able to satisfy basic needs, among other needs and are defined as “all attributes or aspects of the natural environment, human health and resources”. Environmental goods are also known as “Safeguard Subjects” or “areas of protection” according to the ISO 14040 LCA standard [17]. The limited scope of this assessment includes impacts to environment goods that satisfy basic needs rather than more comprehensive impact. Please see Table *1*.

General impact valuation quantifies a delineated process of cause-and-effect mechanisms between and or safeguard subjects as follows. Safeguard subjects or a are measured by their quality. The quality of can increase or decrease. The measurement of their quality is in units of capacity to satisfy basic human needs based on current trajectories, resources, and population growth. Damage are quantified as decreased quality by way of decreased production capacity or preservation and restoration costs. Damage arrives to safeguard subject by way of pathways. pathways take multiple forms that denote specific environmental outcomes or impacts. Environmental outcomes are translated into economic outcomes based on the quantity of production capacity decrease or preservative or restoration costs.

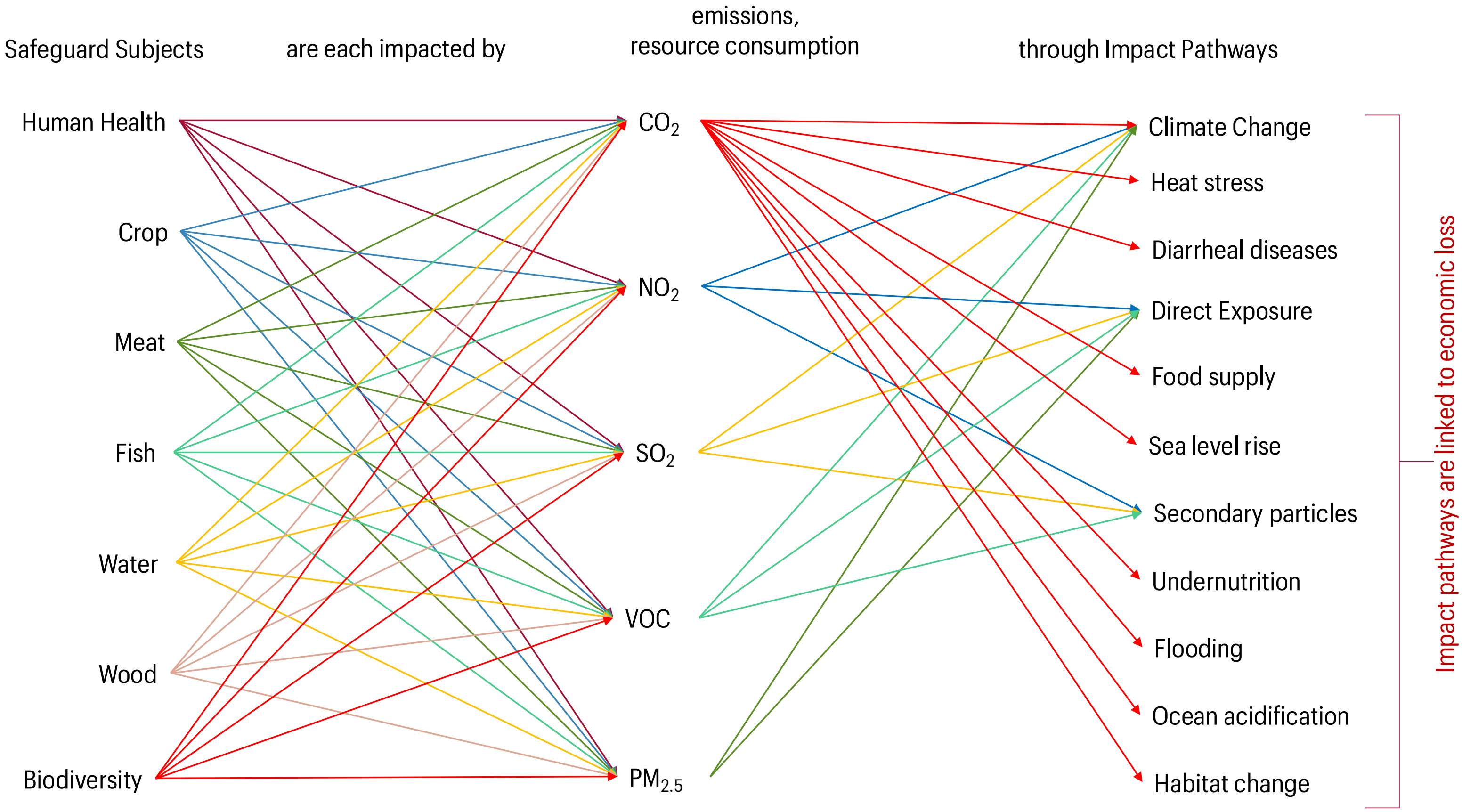

Figure 8 | Safeguard Subjects map to Impact Pathways

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[17] ISO 14040:2006. Environmental management — Life cycle assessment — Principles and framework.

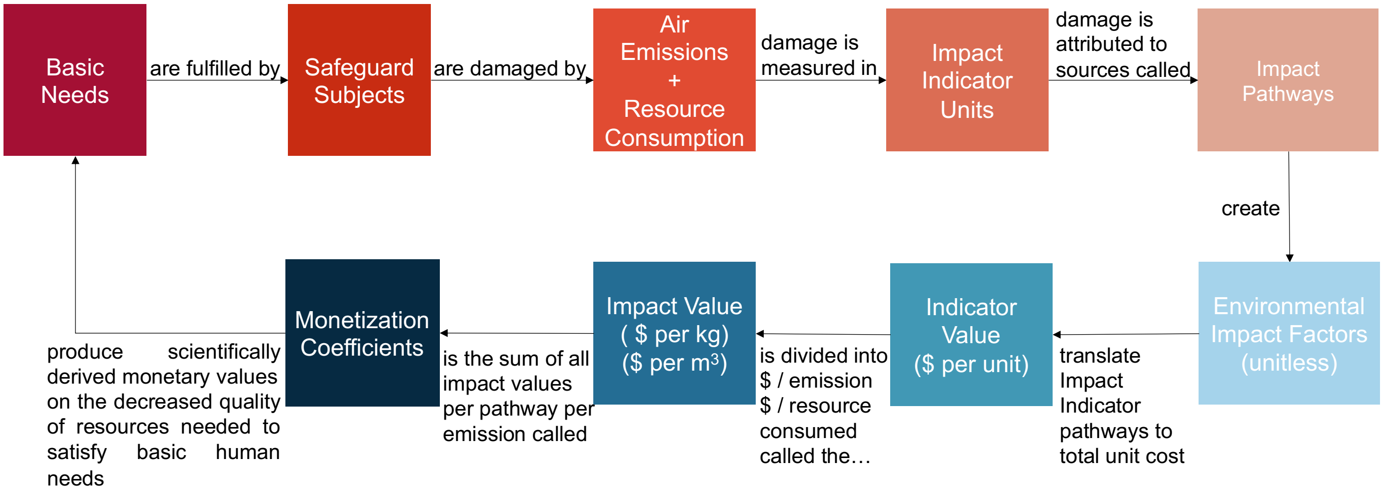

Figure 9 | Safeguard Subjects map to Impact Indicators

A precondition for the generation of economic value is physical production. To generate physical production, humans must have a set of basic needs met. Environmental impact valuation concerns the mapping of basic human needs to impacts that may alter the state of resources that have the capacity to satisfy basic human needs. The inability to satisfy basic human needs results in decreased human productivity and, as a secondary effect, decreased economic value. Environmental impact valuation assesses a monetary value or economic cost on decreased human productivity due to basic needs privation or altered state of resources projected into the future.

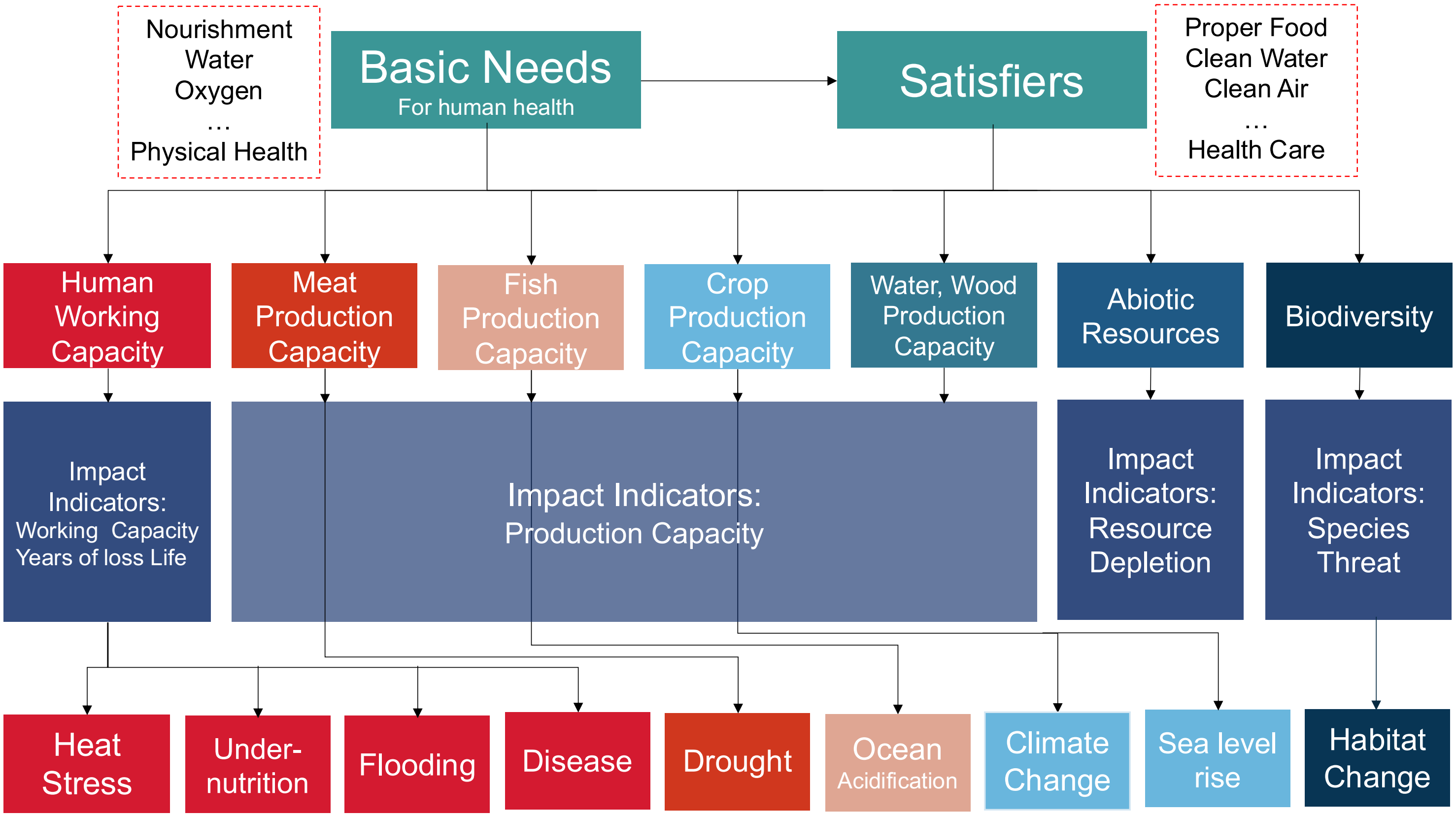

Figure 10 | Impacts on Basic Needs by Safeguard Subject

Environmental Goods are called 'Safeguard Subjects'

Safeguard Subjects are measured by their quality. Their quality is measured through a series of state indicators called 'Impact Indicators'. A decrease in their quality results in an economic loss. This economic loss is quantifiable as a loss in productivity, decrease in resources or preservation, conservation, and restoration costs. Quality decreases result in a measurable, quantifiable monetary economic impact.

Table 1 | Summary of Safeguard Subjects and Impacts

Safeguard Subjects

Environmental Goods	Definition	Environmental Impacts
Human Health	**Impact valued:** decrease in working capacity **Impact Indicator:** decreased performance (hours) **Monetary value:** cost of labor	Climate change, water pollution, land use, toxicity...
Crop	**Impact valued:** decrease in production capacity **Impact Indicator:** decreased production (kg of crop) **Monetary value:** producer price	Soil degradation, air pollution, climate change, land use
Meat	**Impact valued:** decrease in production capacity **Impact Indicator:** decreased production (kg of meat) **Monetary value:** producer price	Soil degradation, climate change, land use, toxicity
Fish	**Impact valued:** decrease in production capacity **Impact Indicator:** decreased production (kg of fish) **Monetary value:** producer price	Acidification, eutrophication, climate change, toxicity
Water	**Impact valued:** decrease in production capacity **Impact Indicator:** decreased production (m^3 of water) **Monetary value:** producer price	Climate change, water pollution, land use
Wood	**Impact valued:** decrease in production capacity **Impact Indicator:** decreased production (m^3 of wood) **Monetary value:** producer price	Climate change, air pollution, land use
Biodiversity	**Impact valued:** decreased biodiversity **Impact Indicator:** share of threat to red-listed species **Monetary value:** preservation costs	Land use, toxicity
Abiotic Resources	**Impact valued:** decrease in resources **Impact Indicator:** extraction from present reserves (kg) **Monetary value:** sustainable alternative substitution cost	Mining

Valuation Methodology

The purpose of a corporate environmental impact valuation is to determine and account for the monetary values of environmental impacts from emissions and use of natural resources that occur throughout corporate operations. Monetary valuation is relevant and applicable to a wide range of stakeholder, corporate, and investor use cases in determining an estimate of environmental risk exposure of operations and investments and optimization of decision making around those risks. The outcome of an impact valuation is to provide a degree of measurement towards environmental and financial outcomes of a given business strategy.

The ISO 14008: 2019 Standard[18] on the monetary valuation of environmental impacts is applied for the scope of this corporate environmental valuation to lend transparency to calculations. The ISO 14008: 2019 standard applies consensus, default valuation procedures for global, intergenerational impacts. The guiding principles of ISO 14008: 2019 are accuracy, completeness, consistency, credibility, relevance, and transparency. The majority of the monetary and impact pathway coefficients are from the EPS 2019 models. All monetary valuations are FAO world market prices or related to OECD average inhabitant income and average productivity. Estimates and assumptions are supplemented by scientific literature and IPCC report scenarios. IPCC reports scenarios up to 2100 and the impact models applied to the valuation methodology estimate impacts between 2015 and 2100 caused by 1 kg or 1 m^3 of emissions or resource consumed in 2015 for the IPCC reference scenario RCP6.0. RCP6.0 is the higher middle scenario with an estimated global mean temperature increase of 1.3°C by 2050 and 2.2°C to 2100 corresponding to 5920 gigatons of carbon emitted.[7]

Process:

To conduct a Corporate Environmental Impact valuation, the following steps must be taken for each firm to be analyzed:

1. Data collection and management
2. Data pre-processing and verification
3. Apply IWA Valuation Tool
4. Data outcomes analysis and interpretation

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[18] ISO 14008: 2019 Standard | Monetary valuation of environmental impacts and related environmental aspects

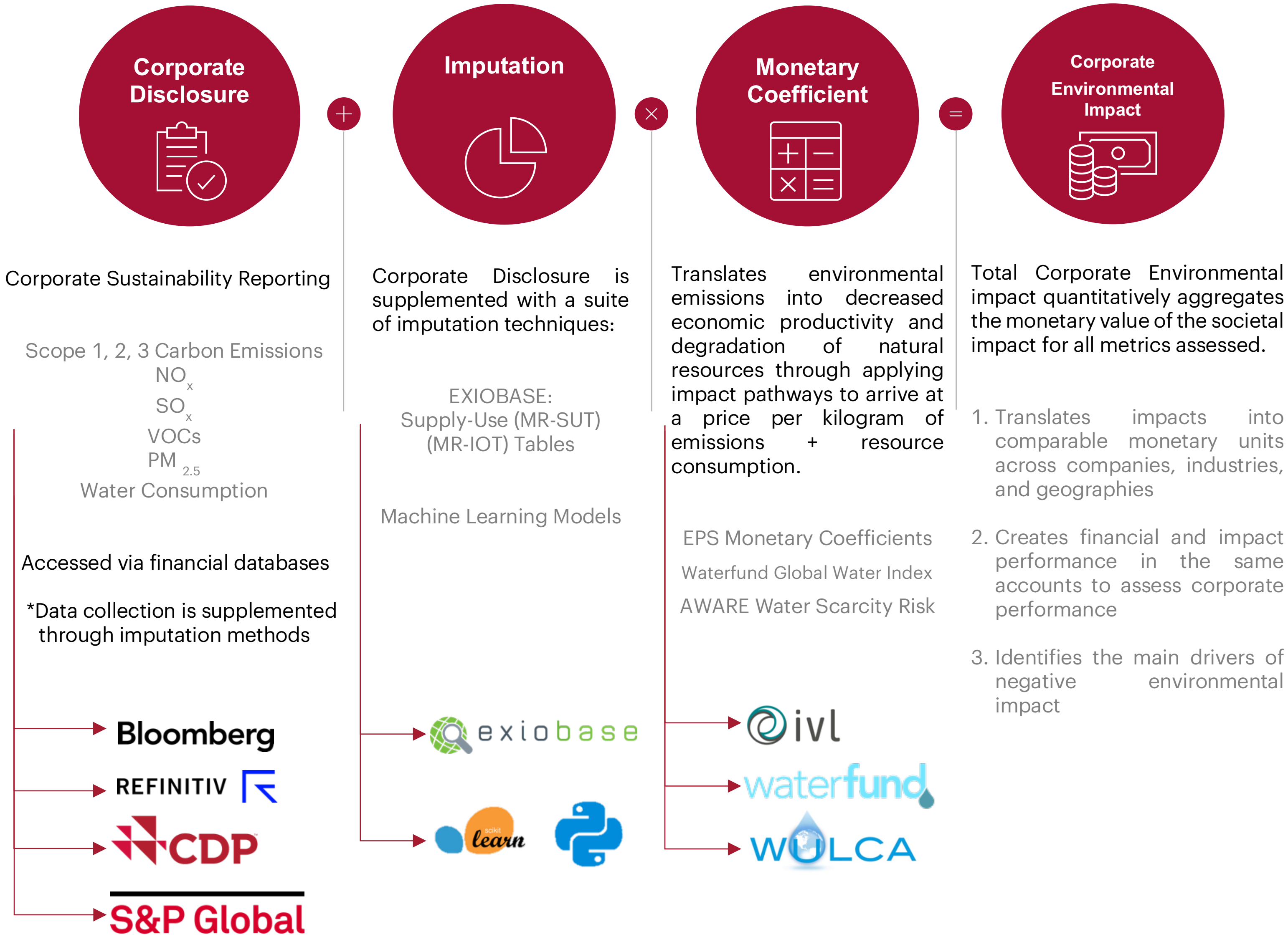
Corporate Environmental Impact | General Modelling Process

The IWA general modelling process takes outputs of corporate natural capital resource inputs to generate environmental outcomes that translate to economic outcomes for various stakeholders measured in currency called monetary valuations.

Definition	Process	Example
Raw energy and resources required for Corporate Operations	**Inputs** Energy, Materials, Water Value Chain Resources Corporate Operations	Electricity purchases, heat, refrigeration, supply chain materials. Combustion fuel for air, vehicle, and marine travel. (Hydrocarbons)
Direct Corporate Disclosure sourced through Financial Databases e.g., Bloomberg, Refinitiv, S&P Capital IQ, CPD emissions and resource use.	**Outputs** Carbon Emissions Non-Carbon Emissions Water, Resource Consumption	Scope 1, 2, 3, carbon emissions from electricity purchases, refrigeration, heat and supply chain. Water, NOx, SOx, VOCs, $PM_{2.5}$, Abiotic Resources
Environmental 'Goods' are 'safeguard subjects'; resources critical for human health. The state of safeguards are measured through loss of economic productivity, and cost of preservation and restoration.	**Monetary Valuation** Translates outputs into monetary cost towards damage of environmental goods	Impact of air pollutants and water scarcity on human productivity, biodiversity, crop production capacity, food and water availability, etc. as measured by scientific models.
Translating emissions released through operations into the monetary loss of economic productivity or degradation of safeguard subjects. Transforming the impact into dollar cost.	**Corporate Environmental Impact** Aggregated monetary value of total societal impacts for all metrics assessed	Monetary cost of proportional environmental damage through corporate operations arrived at by internalizing environmental externalities.

Figure 11 | General Modelling Process

Corporate Environmental Impact | Monetization Methodology



Corporate Disclosure

Corporate Sustainability Reporting

Scope 1, 2, 3 Carbon Emissions
NO_x
SO_x
VOCs
$PM_{2.5}$
Water Consumption

Accessed via financial databases

*Data collection is supplemented through imputation methods

Imputation

Corporate Disclosure is supplemented with a suite of imputation techniques:

EXIOBASE:
Supply-Use (MR-SUT)
(MR-IOT) Tables

Machine Learning Models

Monetary Coefficient

Translates environmental emissions into decreased economic productivity and degradation of natural resources through applying impact pathways to arrive at a price per kilogram of emissions + resource consumption.

EPS Monetary Coefficients
Waterfund Global Water Index
AWARE Water Scarcity Risk

Corporate Environmental Impact

Total Corporate Environmental impact quantitatively aggregates the monetary value of the societal impact for all metrics assessed.

1. Translates impacts into comparable monetary units across companies, industries, and geographies
2. Creates financial and impact performance in the same accounts to assess corporate performance
3. Identifies the main drivers of negative environmental impact

Figure 12 | IWA Monetization Methodology

Corporate Environmental Impact | General Monetization Process

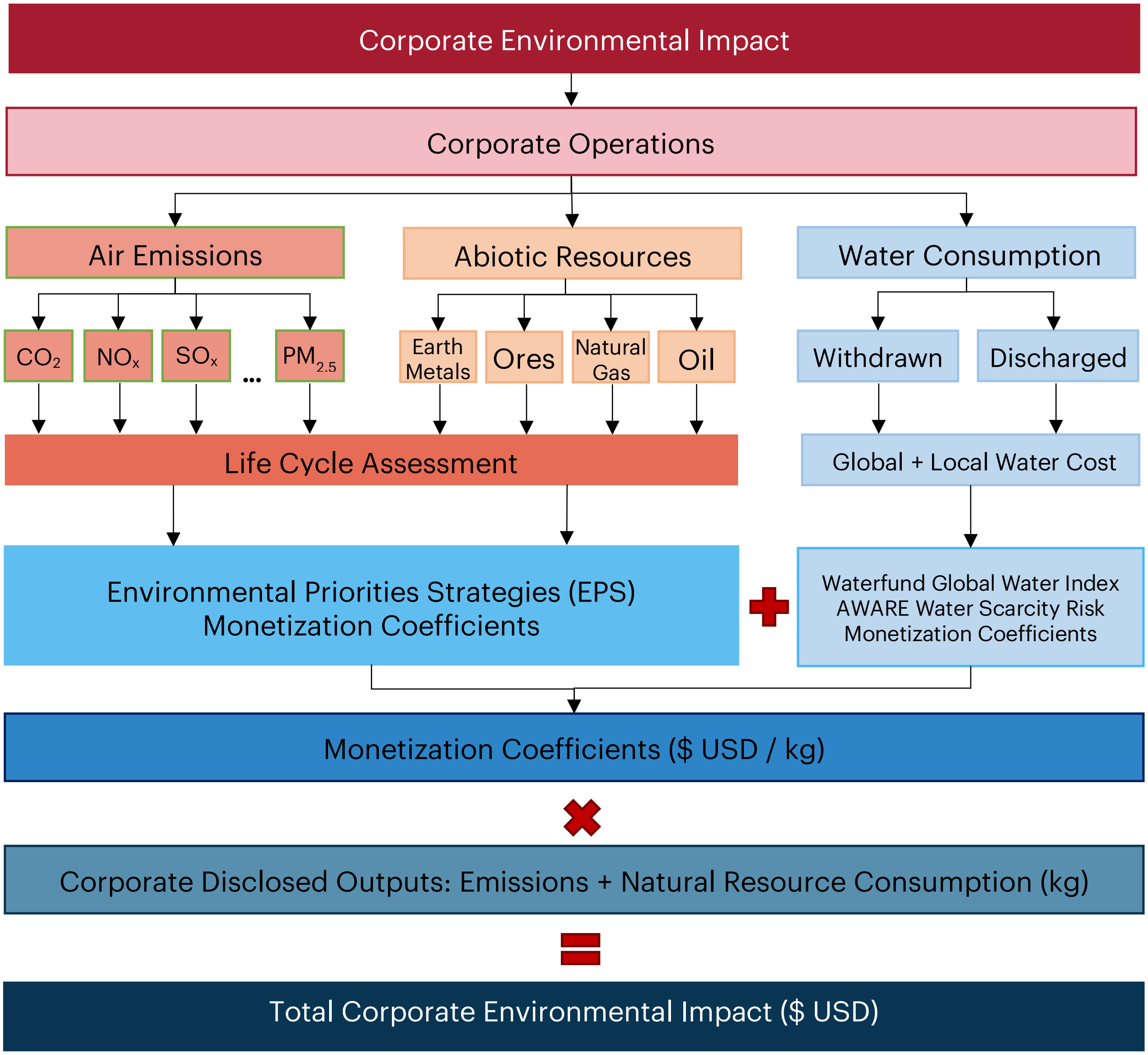


Figure 13 | General Monetization Process.

The monetary valuation of corporate environmental impacts takes the approach of converting corporate resource inputs into environmental emissions and resource consumption. The monetary impact of emissions and resource consumption are evaluated through life cycle assessment. Life cycle assessments across inputs produce environmental and economic outcomes known as monetary valuations of environmental impact.

Data Requirements

Dimensions		Metric	Metric Description
Emissions Data	Emissions	Carbon Emissions Scope 1, 2, 3	Greenhouse gases which contribute to the trapping of heat in the atmosphere e.g., CO_2, CH_4; emissions are split into Scope 1, 2, 3
		NO_x	NO_x contributes to formation of smog, acid rain; NO_x is produced from combustion fuels (hydrocarbons) e.g., car & marine engines.
		SO_x	SO_x contributes to formation of sulfuric acid, acid rain, SO_x is produced from combustion fuels—coal, oil, diesel-- in engines.
		VOCs	Volatile Organic Compounds are air pollutants produced in the manufacture of fuels, paints, pharmaceuticals, and refrigerants.
		$PM_{2.5}$ *	Fine particulate matter is an air pollutant emitted via construction, smokestacks, fires etc. or as a byproduct of $NO_{x,}$ & SO_x in fuels.
	Water	Total Water Withdrawal	Total water diverted for use by the firm
		Total Water Discharge	Total waste/process water discharged by the firm Water is localized by nation of domicile
Classification + Financial Data	Classification	Nation of Domicile	Registered nation of domicile
		GICS Sub-Industry	MSCI Global Sub-Industry Classification Standard
		Facilities of Operation	Location of company-owned/operated facilities
	Financial	Net Revenue	Fiscal Year Net Sales drawn from financial databases
		Operating Income	Fiscal Year Operating Income from financial databases

Figure 14 | Priority Data

Priority data is primarily sourced from corporate disclosures and sustainability reporting. Priority data is accessed via financial databases and supplemented with imputations as a secondary measure.* PM2.5 is sourced only through imputation in current methodology; it is not collected through corporate disclosure.

Given the above specified data, the IWA methodology creates industry level firm-specific profiles. The financial data normalizes firm size and outputs while classification data aims to benchmark performance.

Data Management

Data Requirements

The accessibility and reliability of corporate disclosure is a critical component to measurement. The accuracy of data applied in measurement is crucial for large-scale implementation of monetary valuation of environmental impacts. Furthermore, the application of precise measurements delivers on the need to refine environmental valuation methods. Corporate disclosure of environmental metrics has grown in implementation and is the central component to creating impact weighted accounts. The data requirements to quantify environmental impact are described in Table 1. Financial databases such as Bloomberg and Asset 4 by Refinitiv store the data points in the mnemonics specified.

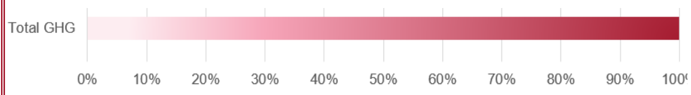
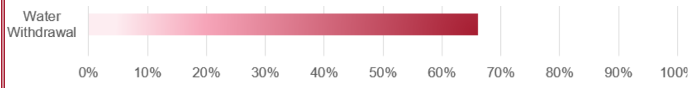
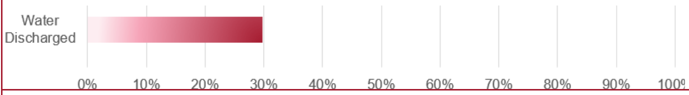
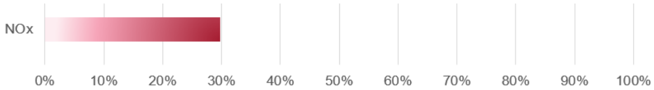
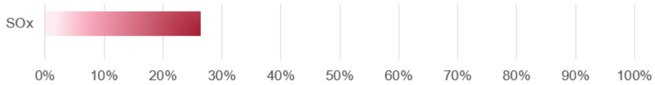
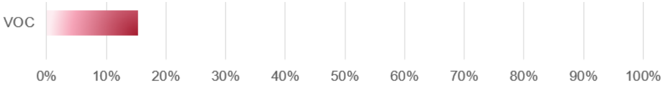
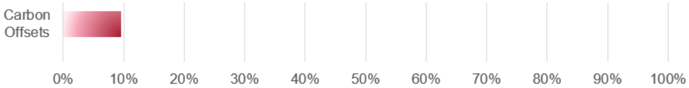
Table 2 | Data Requirements

	Data	Definition	Bloomberg	Refinitiv Asset4
Priority Data	Total GHG Emissions Scope 1 + 2 (metric tons)	Total Greenhouse Gas (GHG) Emission. GHGs: CO_2, CH_4, N_2O.	ES005 (Scope 1 + 2)	ENERDP023 (Scope 1 + 2)
	Water Withdrawal (m^3)	Amount of water diverted for use by corporation.	ES269	ENRRDP054
	Water Discharged (m^3)	Total volume of liquid waste and process water discharged.	ES081	ENERDP057
	Sulphur Oxide (SO_x) (metric tons)	Total amount of Sulphur oxides (SO_x) emitted by corporation.	ES079	ENERDP035
	Nitrogen Oxide (NO_x) (metric tons)	Total amount of nitrogen oxides (NO_x) emitted by corporation.	ES007	ENERDP034
	Volatile Organic Compounds (VOCs) (metric tons)	Total amount of volatile organic compounds emitted by firm.	ES009	ENERDP040
	Carbon Offsets (metric tons)	Total amount of greenhouse gas emissions offset by firm..	ES385	ENERDP097
Addt'l. Data	Primary Facilities of Operations	Buildings owned or operated (lat, long coordinates preferred)		
	Location of Employees	Workforce location by percent (lat, long coordinates preferred)		
	Location of Emissions	Emissions raw or by percent (lat, long coordinates preferred)		
	Location of Water Use	Water consumption location (m^3) (lat, long coordinates preferred)		
	Scope 3 Emissions	Scope 3 emissions by 15 categories (metric tons)		

Data Availability

The relative data availability collected across Bloomberg ESG Index and Refinitiv Asset4 ESG databases is shown below.[19] The data represents firms with a market capitalization of greater than 100 million USD and with reported total greenhouse gas emissions. Employing both databases, the data sample is collected from 2010 to 2019, resulting in 24,276 firm-year observations with data for total greenhouse gas emissions and is denoted as 100% of the sample set. The accuracy of valuations depends largely on data quality. Data quality and access remain a primary barrier in conducting impact-weighted environmental accounting.

Table 3 | Data Availability

Data	Relative Data Availability (%)	Bloomberg	Refinitiv Asset4
Total GHG Emissions Scope 1 + 2 (metric tons)		ES005 (Scope 1 + 2)	ENERDP023 (Scope 1 + 2)
Water Withdrawal (m^3)		ES269	ENRRDP054
Water Discharged (m^3)		ES081	ENERDP057
Nitrogen Oxide (NO_x) (metric tons)		ES079	ENERDP035
Sulphur Oxide (SO_x) (metric tons)		ES007	ENERDP034
Volatile Organic Compounds (metric tons)		ES009	ENERDP040
Carbon Offsets (metric tons)		ES385	ENERDP097

Given the relative scarcity of reporting across environmentally and financially material metrics such as NOx, SOx, and VOC, imputations are employed to measure firms equally. Imputations contribute a degree of uncertainty within the valuation and are used only as a second measure. The imputation process is closely detailed in the following section.

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[19] Freiberg, D., Park, D.G., Serafeim, G. and Zochowski, R., 2021. Corporate environmental impact: measurement, data and information. Harvard Business School Accounting & Management Unit Working Paper, (20-098).

Data Availability

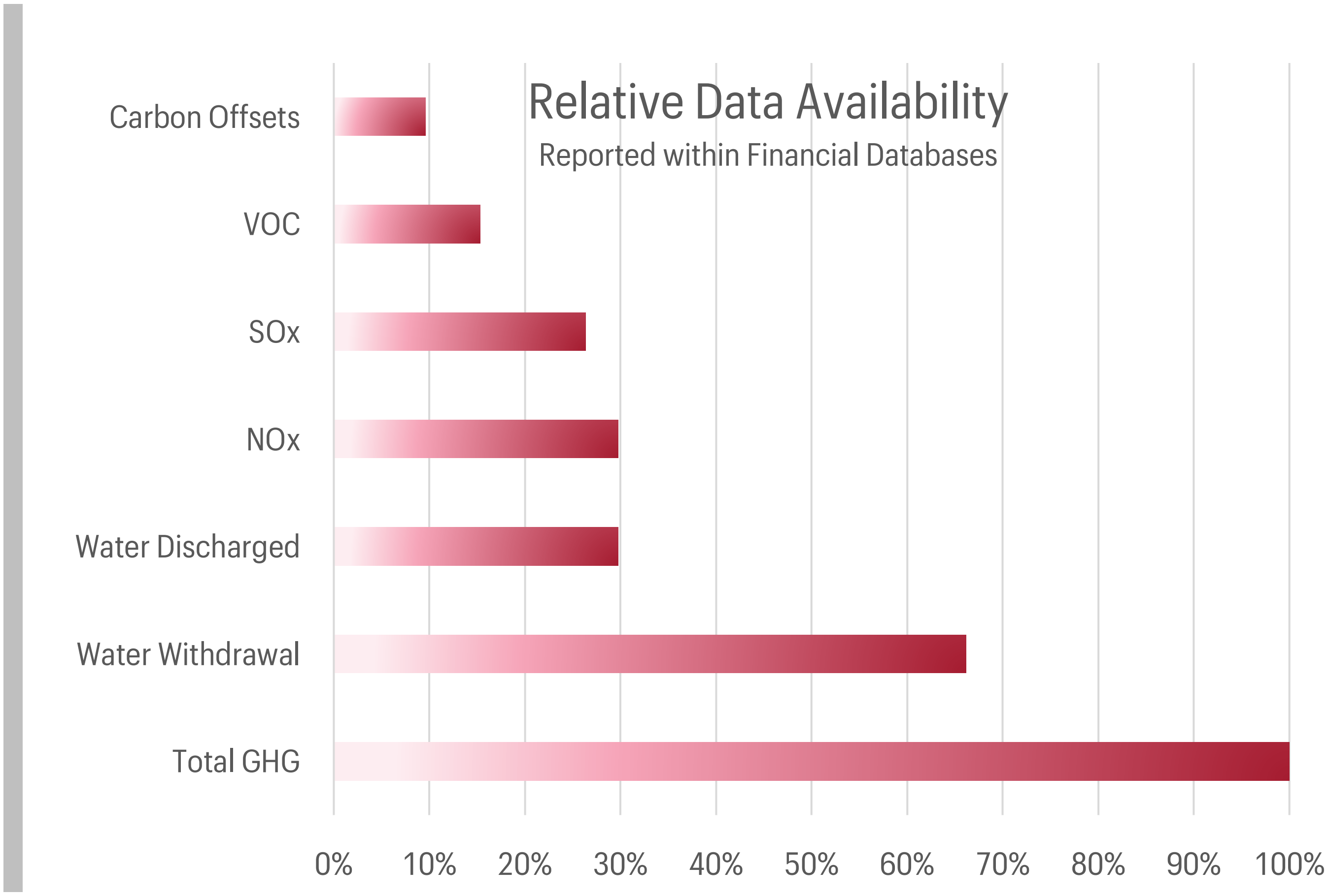
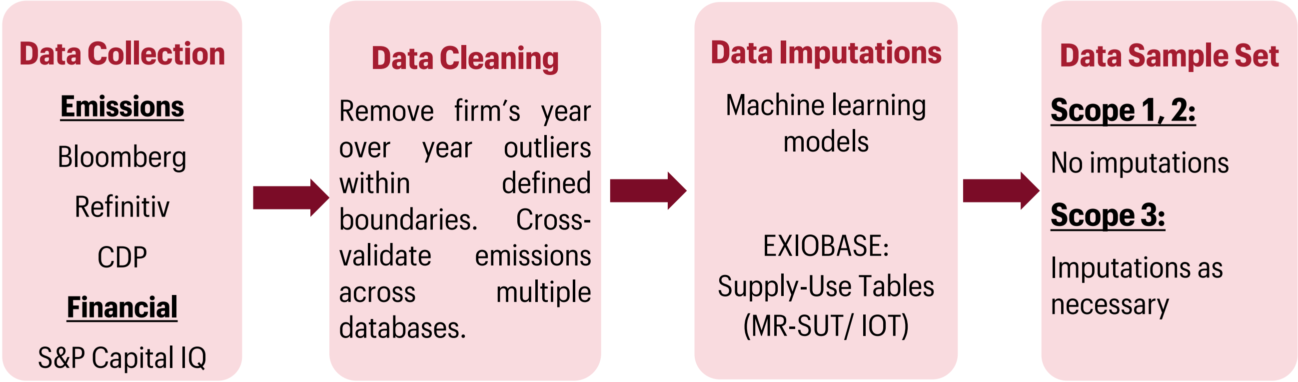


Figure 15 | Relative ESG Metric Availability

within proprietary financial databases such as the Bloomberg ESG Index and the Refinitiv Asset4 financial databases. The data represents firms with a market capitalization of greater than 100 million USD and with reported total GHG (Scope 1 + Scope2) . Firms without reported Total GHG emissions are excluded from the sample to ensure robustness of the results given the high monetary valuation associated with GHG emissions. Employing both databases, the data sample is collected from 2010 to 2019, resulting in 24,276 firm-year observations with data for Total GHG emissions and is denoted as 100% of sample set.

- The accuracy of valuations depend largely on data quality.
- Data quality and access remain a primary barrier in conducting impact-weighted environmental accounts.
- Imputations allow us to measure comparably and at scale. Notwithstanding, imputations contribute a degree of uncertainty within the valuation and are used as a second measure.

Data Imputations



Data Collection

Emissions

Bloomberg

Refinitiv

CDP

Financial

S&P Capital IQ

Data Cleaning

Remove firm's year over year outliers within defined boundaries. Cross-validate emissions across multiple databases.

Data Imputations

Machine learning models

EXIOBASE: Supply-Use Tables (MR-SUT/ IOT)

Data Sample Set

Scope 1, 2:

No imputations

Scope 3:

Imputations as necessary

Metric	Imputation Methodology	Current State
Scope 1, 2	IWA methodology only collects primary Scope 1, 2 reporting for valuation. **No imputations are performed.**	Firm primary disclosure, or financial database estimate. No imputations through IWA.
Scope 3	Machine learning models can be used to complete corporate reporting and weight carbon emissions equally across firms	Small sample set of reported emissions across Scope 3. Low corporate disclosure results in increased machine learning prediction error
NO_x, SO_x, VOC	NO_x, SO_x, VOC imputed via EXIOBASE: database of 44 countries, 5 World Regions, 164 industries, 417 emission categories and over 1000 emission, material + resource categories	Assumption that emissions scale with sales; limitations with location of operations. Machine learning model under development.
$PM_{2.5}$,NMVOC	$PM_{2.5}$, NMVOC imputed only via EXIOBASE, no corporate disclosure is assessed as a direct input.	Pro-rata portion of industry total is allocated to a firm by ratio of revenue to total industry output per firm year.
Water Withdrawal Water Discharged	Only firms with reported "water withdrawal" at a minimum are assessed. When water withdrawal data is available, yet water discharged is missing, calculate the median ratio of water discharged to water withdrawal per industry-year and multiply firm water withdrawal with the industry-year median water. Air emissions to water are assessed via EXIOBASE.	Geospatial localization of water use by facilities of operations is currently under development. Provides granular assessment of water scarcity risk

Increasing 'degree' of imputation

Figure 16 | Data Imputations

Corporate Emissions

IWA's Corporate Environmental Impact Methodology integrates leading ISO standards, scientific research, and financial analysis to create an empirical and systematic methodology capable of assessing a monetary value on the environmental costs of corporate operations. IWA's methodology employs the following resources in creating the integrated methodology:

- Environmental Priorities Strategies (EPS)
- EXIOBASE Version 3
- Waterfund Global Water Price Index
- AWARE Water Footprint Analysis

Environmental Priorities Strategies

The Environmental Priorities Strategies (EPS) [20] methodology was developed as a collaboration between the IVL Swedish Environmental Research Institute [21], Volvo and the Swedish Life Cycle Center [22]. EPS data and models are the product of 30 years of scientific research working towards the development of a life cycle assessment (LCA) tool for designers. Monetary valuation of environmental impacts was initially developed as a decision-making tool to assess the cost of materials, processes, and parts in the design of sustainable products. The EPS impact assessment (characterization and weighting) method applies a life cycle assessment (LCA) analysis to emissions and use of natural resources expressed as ELU (Environmental Load Units) and quantified as an externality corresponding to monetary damage cost. The ISO standard 14008: 2019 [18] was developed for the purpose of standardizing monetary valuation of environmental impacts and offers the language and structure to specify the monetary value of environmental impacts.

EXIOBASE Version 3

EXIOBASE (Version 3) is a global, detailed Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT), developed, and financed by European research

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[20] Environmental Priority Strategies in product design (EPS).
[21] IVL Swedish Environmental Research Institute.
[22] Swedish Life Cycle Center.

centers and applies European research frameworks15. EXIOBASE provides a macroeconomic consumption-base sustainability accounting database of products, emissions and resources aligned with the accounting systems proposed by the United Nations (UN) System of Environmental-Economic Accounting (SEEA). EXIOBASE provides analytical production-related impacts and consumption-based accounting of, for example, where resources are extracted from, where resources are used and where emissions are discharged. While country-reported data on production and consumption processes is readily accessible, EXIOBASE reconciles the interrelations of global macroeconomic estimates with country level data given the dynamic supply chain complexities that the liberalization of international trade that has given rise to. Through this, EXIOBASE has constructed a reliable environmental accounting system that facilitates time series analysis of global production and consumption processes with a high and consistent level of sector detail. EXIOBASE has in depth coverage for 28 EU member economies, 16 major economies, 5 rest of the world regions that span 163 industries and over 1000 emissions, materials and resource categories, accounting for ~90% of global gross domestic product.

Machine Learning Algorithms

An organization's carbon emissions are comprised of three categories: scope 1, 2, and 3. Scope 1 greenhouse gas emissions are classified as direct emissions from a company's owned or controlled assets. Scope 2 greenhouse gas emissions are classified as indirect emissions from purchased heat, cooling or energy generated offsite and consumed by the company. Scope 3 emissions (often referred to as value chain emissions) are indirect emissions generated from activities conducted using assets not owned by the reporting company that are involved in the production and usage of the reporting company's product or service. Scope 3 emissions are produced from a broad diversity of sources and processes including emissions associated with purchased goods and services, employees commuting, waste generated from operations, processing of sold products, and use of sold products.

Scope 1 and 2 emissions are the most extensively reported. Scope 1 emissions can be calculated using internal activity metrics. Scope 2 emissions can be calculated using utility consumption by energy source combined with emission conversion factors. By comparison, scope 3 emissions are more difficult to understand and quantify. The data needed to quantify these emissions frequently comes from third-parties or secondary sources. Challenges such as these are common in quantifying the different types of scope 3 emissions. Despite the challenges in measuring and mitigating scope 3 emissions, these emissions are significant. It is common for scope 3 emissions to account for a substantial share of a firm's total emissions footprint. Scope 3 emissions represent a substantial future climate transition risk as well as a significant opportunity to motivate future emissions reductions. Within the IWA methodology, the estimation of Scope 3 emissions are augmented through the application of machine learning algorithms.

Data Collection

Data Base

Emissions Data

CDP Climate Change Questionnaire 2013-2020

CDP

Financials

S&P Compustat
Bloomberg

S&P Global
Bloomberg

Targets

Scope 3 Emissions

Upstream

1. Purchased Goods
2. Capital Goods
3. Fuel and Energy
4. Upstream Transportation
5. Waste generated
6. Business Travel
7. Employee Commuting
8. Upstream Leased Assets

Downstream

9. Downstream transportation
10. Processing of sold products
11. Use of sold products
12. End of life treatment of sold products
13. Down. leased assets
14. Franchises
15. Investments

Features

Stock

Total Assets
Net Property, Plant, Equip.
Common Equity
Market Capitalization
Number of Employees

Flow

Sales
Cost of Goods Sold
Selling, General, Admin Exp.
Operating Expense
Operating Income
Capital Expenditures

Ratios

Return on Sales
Asset Turnover
Capital Intensity
Capital Renewal
Age of Capital Assets
Inventory Turnover Ratio
Market to Book

Emissions

Scope 1
Scope 2

Classification

GICS Sub-Industry
Nation of Domicile

Data Processing

Model Variables

Pre-Processing

Eliminate

Firms where:

- *Reported Scope 1 = 0*
- *Reported Scope 2 = 0*
- *Missing predictive features*
- *Outliers:*
  Target values > 1 billion

Filter

- *Upper and low boundary limits are winzorized to 1st and 99th percentile*

For Training Sub-Sets

- *Keep reported zeros*
  Exclude reported zeros

Missing Values

- *K-neighbor imputation of financial variables*

Prediction Model

Benchmark

Empirical Estimation

1 Ordinary Least Squares (OLS)

2 Gamma Generalized Linear (GLM)

ML Baseline

3 k-NN Algorithm (kNN)

Base Learners

Linear Models

1 Elastic Net Regressor
- Ridge Regressor
- Lasso Regressor

Non-Linear Model

Random Forests
Adaptive Boosting
Xtreme Gradient Boosting

Stacked Regressors

Stacked Regressor

1 Base Learner
- Elastic Net Regressor

2 Meta Estimator
- Random Forest Regressor

Recursive Feature Elimination
Feature Selection Mask:
1 Lasso CV
2 Random Forest
3 Gradient Boosting Regression

Log Transformation

Standard Scaler for Normally Distributed Features

Bayesian Hyperparameter Optimization

1 max_depth
2 min_samples_leaf
3 learning_rate
4 n_estimators

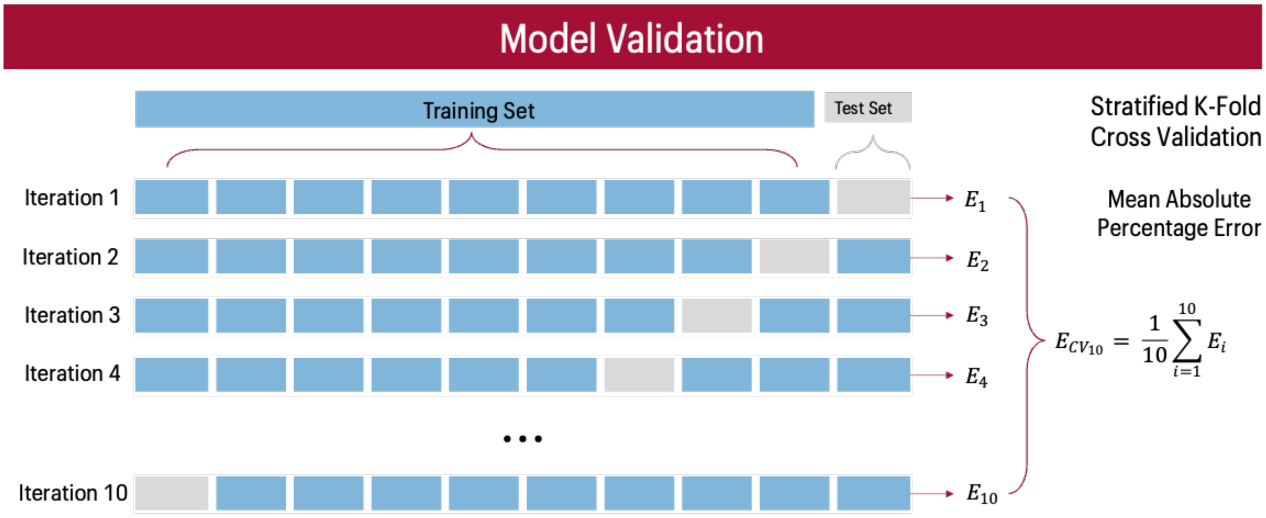

Figure 17 | Machine Learning Algorithms

The IWA methodology incorporates predictive features that are widely available across publicly listed firms found within proprietary financial databases. Industry-specific energy production data may be incorporated in future improvements to the model. To achieve scalability and practicality of the model, widely available financial features and reported emission features are prioritized. Reported scope 3 emission types can be predicted with higher accuracy using Adaptive Boosting machine learning algorithms relative to linear regression models and other supervised machine learning algorithms. [23]

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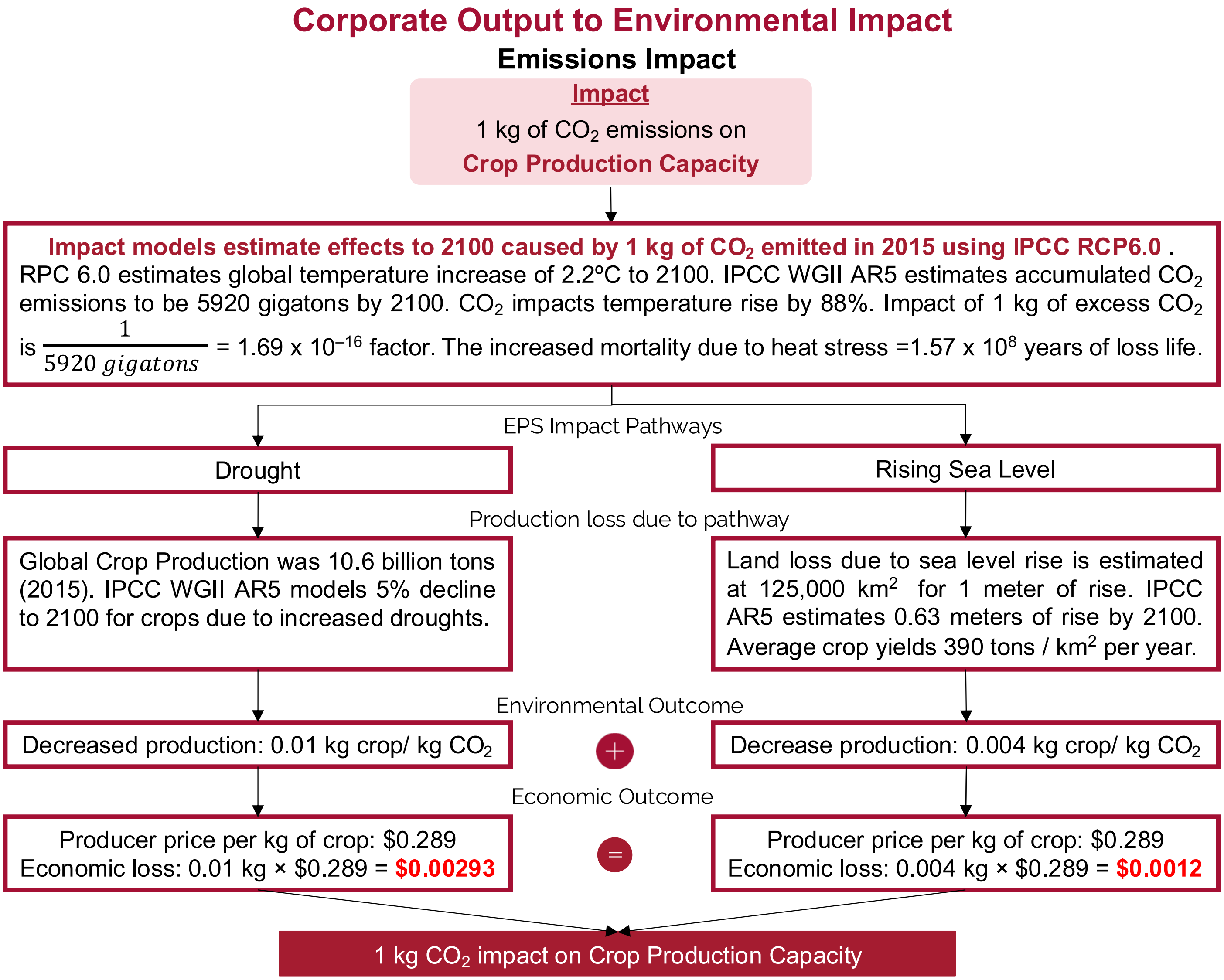
[23] Serafeim, George, and Gladys Vélez Caicedo. "Machine Learning Models for Prediction of Scope 3 Carbon Emissions." Harvard Business School Working Paper, No. 22-080, June 2022.

The path to arriving at an economic outcome given a quantity of air emissions requires the integration of scientific climate modeling with macroeconomic data as detailed in the worked example below. When brought together, a monetary value denoting economic cost is quantified per each kilogram of air emission or air pollutant produced. The safeguard subject used in this example is “Crop” and “Impacts” are defined as damage brought on as decreased quality or quantity of the safeguard subject impacted as shown in Figure 10. Crops and the ability to produce crops are impacted due to soil degradation, air pollution, climate change and land use. Soil degradation, air pollution and climate change are caused by air emissions and air pollutants. Each type of emission and pollutant will produce an impact through impact pathways, of which there are multiple. The impact valued is crop production capacity, the impact indicator, also known as state indicator, is decreased production in terms of kilograms of crop and the monetary value used is the producer price per kilogram of crop according to the FAO average [7]. Below is denoted the decrease to crop production capacity due to 1 kg of CO_2 emissions.



Corporate Output to Environmental Impact

Emissions Impact

Impact
1 kg of CO_2 emissions on
Crop Production Capacity

Impact models estimate effects to 2100 caused by 1 kg of CO_2 emitted in 2015 using IPCC RCP6.0 . RPC 6.0 estimates global temperature increase of 2.2ºC to 2100. IPCC WGII AR5 estimates accumulated CO_2 emissions to be 5920 gigatons by 2100. CO_2 impacts temperature rise by 88%. Impact of 1 kg of excess CO_2 is $\frac{1}{5920\ gigatons}$ = 1.69 x 10^{-16} factor. The increased mortality due to heat stress =1.57 x 10^{8} years of loss life.

EPS Impact Pathways

Drought

Rising Sea Level

Production loss due to pathway

Global Crop Production was 10.6 billion tons (2015). IPCC WGII AR5 models 5% decline to 2100 for crops due to increased droughts.

Land loss due to sea level rise is estimated at 125,000 km^2 for 1 meter of rise. IPCC AR5 estimates 0.63 meters of rise by 2100. Average crop yields 390 tons / km^2 per year.

Environmental Outcome

Decreased production: 0.01 kg crop/ kg CO_2

+

Decrease production: 0.004 kg crop/ kg CO_2

Economic Outcome

Producer price per kg of crop: $0.289
Economic loss: 0.01 kg × $0.289 = **$0.00293**

=

Producer price per kg of crop: $0.289
Economic loss: 0.004 kg × $0.289 = **$0.0012**

1 kg CO_2 impact on Crop Production Capacity

Figure 18 | Production capacity decrease as a function of CO_2 emissions

CO_2 emissions impact global climate through temperature rise. A rise in global temperatures leads to a higher incidence of drought, as well as rising sea levels. Drought and less arable land due to land loss via sea level rise will directly impact global crop yields. Therefore, two impact pathways that lead to decreased crop production capacity due to CO_2 emissions are drought and sea level rise. Estimates of global GHG emissions through 2100 are modeled using the IPCC WGII AR5 RPC 6.0 mid-range scenario, which predicts an increase of 2.2° C by 2100 in accordance with 5920 gigatons of CO_2 emissions [7]. The level of drought and sea level rise are also in accordance with IPCC AR5 model estimates to 2100.

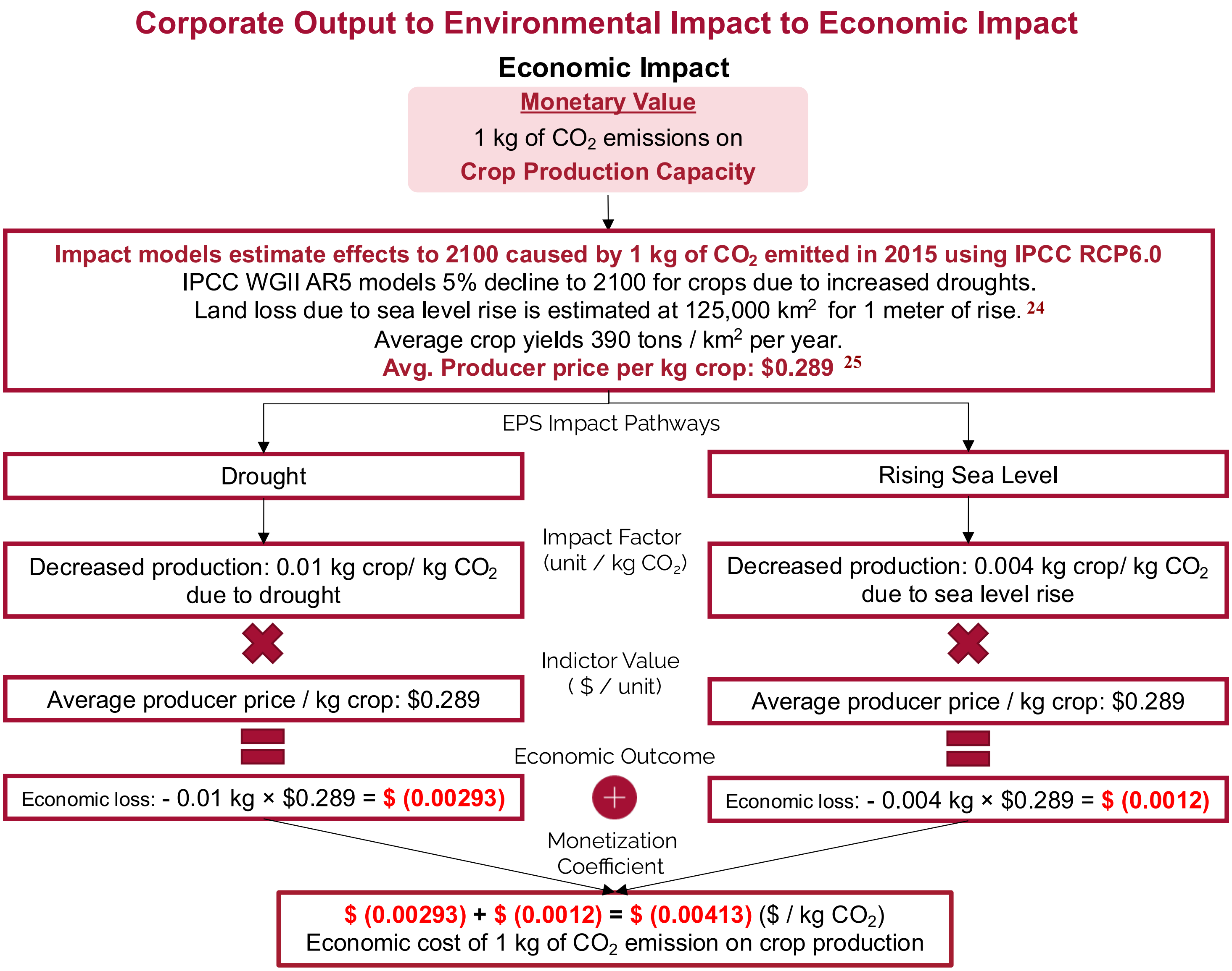


Figure 19 | Economic loss on production capacity by 1 kg of CO2 emissions

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[24] Bosello et al. (2011). Economic impacts of climate change in Europe: Sea-level rise. Climatic Change. 112. 63-81.
[25] FAO. UN Food and Agriculture Organization.

FAO estimates 10.6 billion tons of global crop production in 2015. IPCC WGII AR5 estimates an average 5% decline (1% per decade) until 2100 for major cereals due to increased droughts. The calculation estimates a production capacity loss of 60 billion tons of crop between 2015 – 2100.

$$\frac{Total\ crop\ production\ capacity\ loss_{drought}}{Total\ CO_2\ emissions\ 2015\ to\ 2100} = \frac{(-\ 60\ gigatons\ )}{(5920\ gigatons)} = -\ 0.0101\ \frac{kg\ crop}{kg\ CO_2}$$

Bosello et al. estimates land loss from sea level rise to be 125,000 km^2 and the average FAO crop yield for rice is 3.9 tons per year. The calculation estimates a production capacity loss of 24.4 billion tons of crop between 2015 – 2100.

$$\frac{Total\ crop\ production\ capacity\ loss_{sea\ level\ rise}}{Total\ CO_2\ emissions\ 2015\ to\ 2100} = \frac{(-\ 24\ gigatons\ )}{(5920\ gigatons)} = -\ 0.004\ \frac{kg\ crop}{kg\ CO_2}$$

This process must be repeated for each safeguard subject that is impacted by each emission. Total environmental impact is arrived at through multiple impact pathways and each pathway must be accessed.

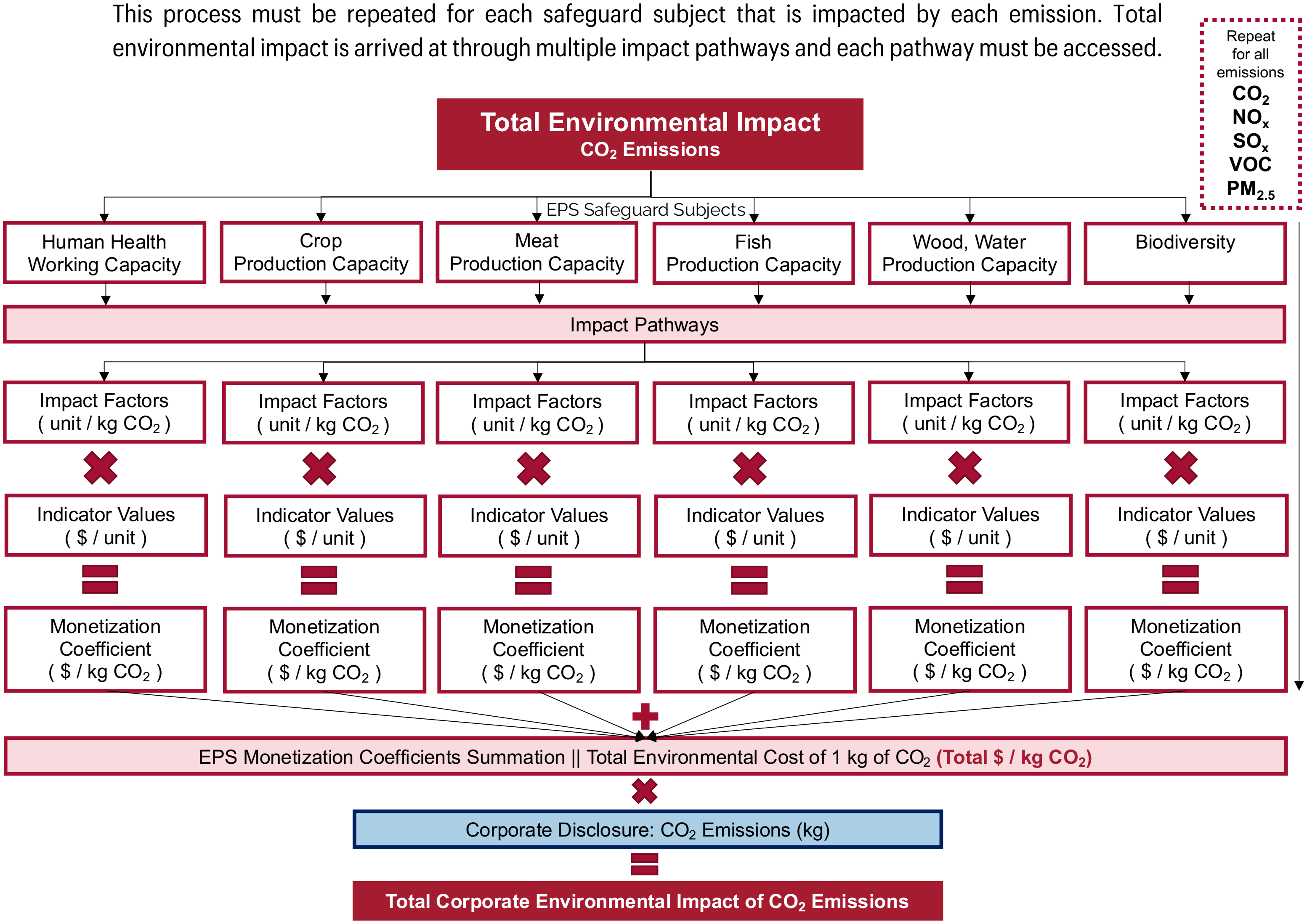

Figure 20 | Modeling Impacts by EPS methodology

Corporate Water Cost

The IWA water methodology delineates a three-tier framework for assessing the cost of corporate water consumption dependent on data availability. Water consumption costs are sensitive to location of use. The IWA tiered approach provides increasing levels of localized water consumption costs using water risk scarcity metrics and relies on accurate data on the geographic location of water consumption as well as on data of water cost in different geographies. The IWA tiered approach is dependent on data availability and provides precision measurements that yield a high geo-spatial resolution of localized water impacts. By applying localized water valuation firms can map environmental impact across geographies, identify localities posing significant water scarcity risk and manage resource allocation. [26] Increased levels of localization provide a path forward from current rough estimates, which, while being useful as an approximation in the short term, lack the granularity required to drive precision measurements within the field of comparative corporate environmental performance. The IWA water methodology uses the resources outlined below.

Waterfund Global Water Price Index

The Waterfund Water Cost Index [27] provides water costs for six countries globally. The Waterfund dataset provides water production and delivery cost as well as wastewater treatment cost, each of which is composed of operating expenses, depreciation, and non-operating expenses. The total cost of production is calculated as the sum of operating costs, capital costs, and identified subsidies. The total cost of delivery the amount the producer reports as delivered, and excludes water lost either due to system leakage, pilfering, or other forms of loss.

$$Water\ Cost\ Index = \frac{Total\ cost\ of\ production}{Total\ delivered\ freshwater\ volume\ (m^3)} \tag{1}$$

WUCLA AWARE Water Footprint Analysis

The AWARE methodology was constructed through a consensus-based, international collaboration that quantified water scarcity through a life cycle assessment at the watershed level. The AWARE methodology is recommended by the Life Cycle Initiative of UN Environment [28] for mapping water stress risk. The AWARE sub-national metrics network allows for localized Water Scarcity Footprint

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[26] Park, D.G., Serafeim, G. and Zochowski, R., 2020. Measuring the cost of corporate water usage.

[27] Rickards Real Cost Water Index™ calculated by IBM. Global Water Cost Indices.

[28] AWARE (2013). UNEP SETAC Life Cycle Initiative.

calculations as defined by the ISO Standard 14,046: 2014 [29]. The AWARE methodology represents the relative available water remaining per area in a watershed once the human and aquatic ecosystem water demands have been met. The product of this work is a harmonized method for assessing water use through the application of local water footprint metrics. To leverage the granularity of measurement afforded by the AWARE model, the IWA methodology applies water stress metrics calculated by nation of domicile to location of business facility level, dependent of data availability. This sub-national approximation approaches a water-shed level of granularity in terms of water scarcity metrics by localizing and subsequently allocating corporate water consumption by business facility. The global sub-national water scarcity metrics encompass 3428 administrative regions defined monthly as well as annually. This spatial resolution is calculated at the sub-watershed level and along averaged water availability on a monthly time frame.

Tier I:

The IWA Tier I water cost methodology applies AWARE water scarcity risk metrics as country level averages based on firm-reported nation of domicile. The process of localizing water to the nation of domicile introduces a broad national water scarcity risk metric to be applied to all corporate water consumption. Localizing corporate water consumption by nation of domicile has the benefits of ease of data availability, ease of calculation and provides an immediate contextual estimate of water impact. Allocating total corporate water consumption by nation of domicile has the disadvantage of possible over- or underestimation of water costs in nations with high water scarcity risk metrics. Due to the coarse nature of a broad national average, a "very large uncertainty" [30] is introduced in localizing all corporate water consumption by nation of domicile and this approximation carries a large sub-national variance and variability. Large variations in water availability across national geographies also have temporal dependence. Furthermore, additional uncertainty is generated, in substantial part, due to multi-national corporations whose operations span across multiple geographies. Allocating all corporate water consumption to the nation of registered domicile may lead to over or underestimations. Current limitations of this approach are that it is unable to accurately capture the environmental impact of multi-national operations and, oftentimes, nation of domicile operations represents a lesser measure of global operations.

Tier II:

The IWA Tier II water cost methodology applies AWARE water scarcity risk metrics as country level averages based on firm-reported nations of operations. Localization of water stress risk metrics by multiple countries of operations is possible when firm data is disaggregated by countries of operation. Although water is not evenly distributed across geographies, the methodology applies countries of operations as a first approximation. Unfortunately, water consumption by nation of

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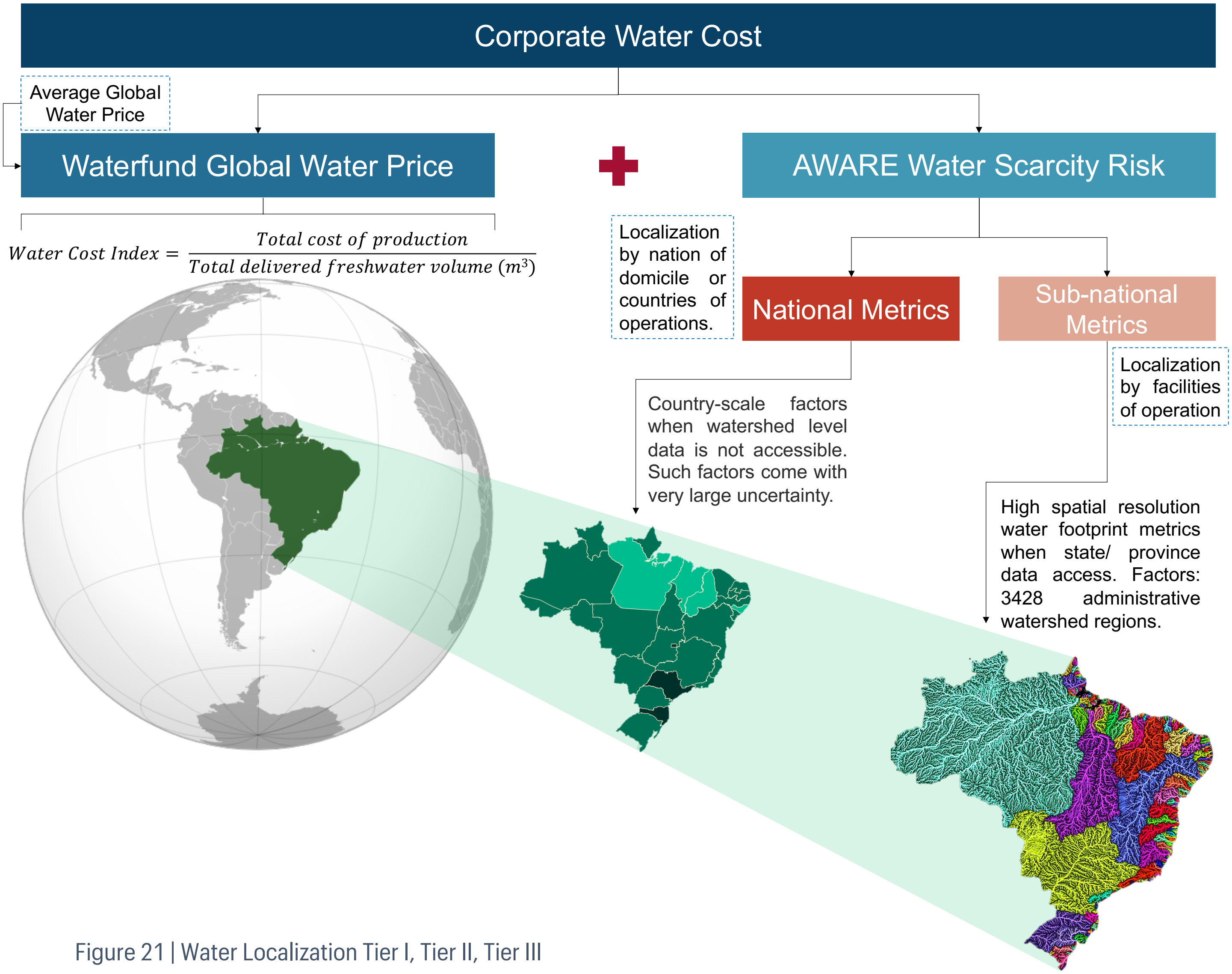
[29] ISO 14046:2014. Environmental management — Water footprint — Principles, requirements and guidelines.

operation are not readily available for most organizations. Scarce organizations provide the geographic location of their water withdrawals and discharges. Therefore, the methodology applies multiple proxies to disaggregate usage at the country level. The process of estimating water consumption by nations of operations extrapolates water usage from firms with available estimates. The methodology is applied to organizations reporting water usage to CDP that have available data on geographic composition of resource consumption as a percentage.

Tier III:

The IWA Tier III water cost methodology applies AWARE sub-national water scarcity risk metrics by business facility. The availability of sub-national water stress risk metrics provides an opportunity to assess water consumption more precisely at the local level and internalize the "hidden liabilities" lost to generalization. The IWA Tier III analysis improves water cost estimations by localizing water impact by business facility in comparison to nation of domicile. The water methodology provides +3,400 global water stress risk metrics are mapped to each firm's business facility.



$$Water\ Cost\ Index = \frac{Total\ cost\ of\ production}{Total\ delivered\ freshwater\ volume\ (m^3)}$$

Country-scale factors when watershed level data is not accessible. Such factors come with very large uncertainty.

High spatial resolution water footprint metrics when state/ province data access. Factors: 3428 administrative watershed regions.

Figure 21 | Water Localization Tier I, Tier II, Tier III

The IWA Tier I water methodology applies the following calculation for water consumption based on nation of domicile:

$$Environmental\ Impact\ of\ Water_{i,t} =$$

$$\sum\begin{pmatrix} Net\ Water\ Consumed_{i,t} \times \\ National\ AWARE\ metric_j \times \\ Water\ Production\ and\ Delivery\ Cost_j \end{pmatrix} + \begin{pmatrix} Net\ Water\ Consumed_{i,t} \times \\ Waterwaste\ Treatment\ Cost_j \end{pmatrix} \qquad (2)$$

The IWA Tier II and Tier III water methodology applies the following calculation for allocation operations at the local level or across multiple nations of operations:

$$Environmental\ Impact\ of\ Water_{i,t} =$$

$$\sum\begin{pmatrix} Net\ Water\ Consumed_{i,t} \times \\ Asset\ Allocation\ Percentage\ _{j,i,t} \times \\ Localized\ AWARE\ metric_j \times \\ Water\ Production\ and\ Delivery\ Cost_j \end{pmatrix} + \begin{pmatrix} Net\ Water\ Consumed_{i,t} \times \\ Asset\ Allocation\ Percentage\ _{j,i,t} \times \\ Waterwaste\ Treatment\ Cost_j \end{pmatrix} \qquad (3)$$

Asset allocation data is used when available. A proxy for asset allocation percentage is Scope 1 emissions disaggregated by business facility. Total reported scope 1 emissions disaggregated by business facility as a percentage is an indication of the scale of operations at each business facility. Scope 1 emissions by business facility is used as a proxy for water consumption at the local level. Scope 1 emissions' breakdown is applied to either indicate the scale of operations in terms of business facilities or multiple countries of operations, depending on data availability.

$$Environmental\ Impact\ of\ Water_{i,t} =$$

$$\sum\begin{pmatrix} Net\ Water\ Consumed_{i,t} \times \\ Scope\ 1\ Allocation\ Percentage\ _{j,i,t} \times \\ AWARE\ metric_j \times \\ Water\ Production\ and\ Delivery\ Cost_j \end{pmatrix} + \begin{pmatrix} Net\ Water\ Consumed_{i,t} \times \\ Scope\ 1\ Allocation\ Percentage\ _{j,i,t} \times \\ Waterwaste\ Treatment\ Cost_j \end{pmatrix} \qquad (4)$$

Using the above calculation, the IWA methodology provides a latitude-longitude level of granularity where water stress risk is derived from the closest associated watershed region from business facility by minimal distance calculation.

Water Consumption Imputation

To perform water imputations in the absence of firm-reported water consumption, the Exiobase Factors of Production water table with national sub-industry disaggregation is applied. The Exiobase Factors of Production water tables model water consumption as follows:

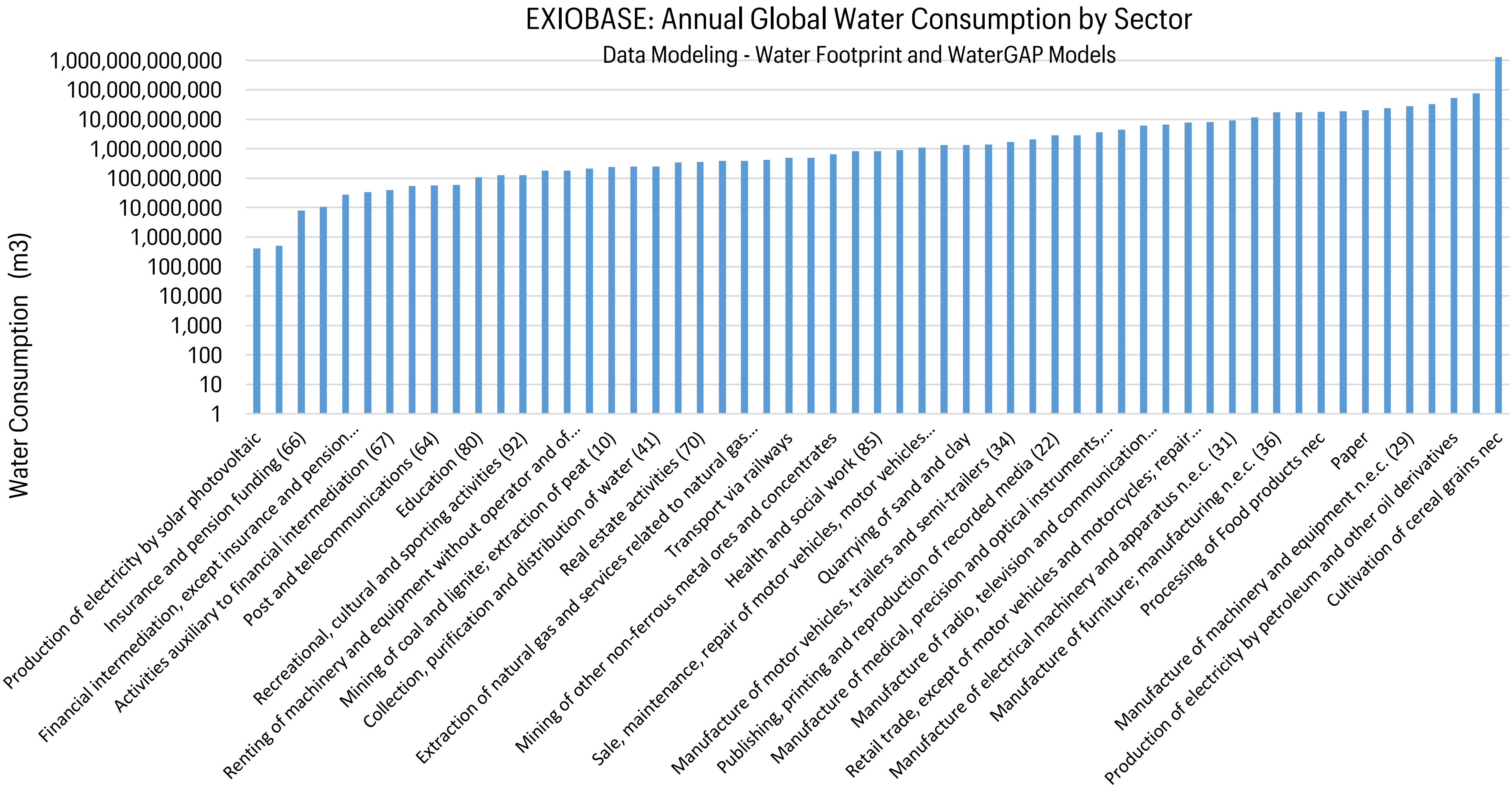


Figure 22 | Annual Global Water Consumption by Sector

The sectors listed in Figure *22* provide data across 5 broad sector classifications:

- Agricultural Use
- Livestock Breeding
- Electricity Production
- Domestic Use
- Manufacturing Sectors (Food products, Tobacco, Textiles, Pulp, Chemicals etc.)

Water consumption modeling and imputation cannot be meaningfully aggregated to sectors beyond the above due to lack of modeling techniques [15]. To apply the Exiobase imputation for the reliable sectors above, it is necessary to first disaggregate a firm's share of regional industry revenue within operating localities. Attribution of water consumption at the local level is achieved by defining by sales by region, which is taken to be proportional to the firm's Scope 1 emission's percentage breakdown.

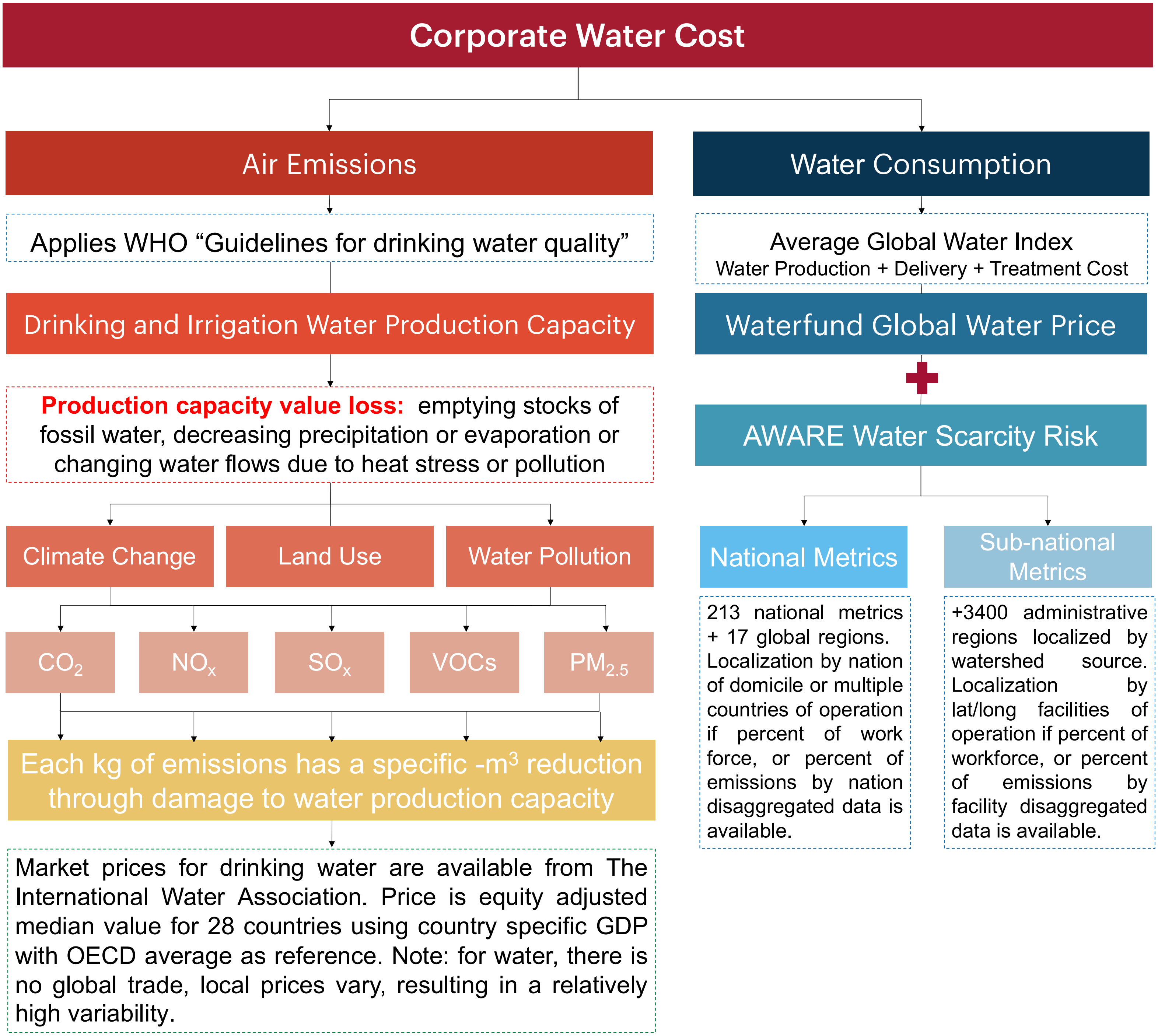
$$Sales\ by\ Region = (Firm\ Year\ Net\ Revenue\ \times Scope\ 1\ Emissions\ Location\ Based\ Percentage) \tag{5}$$

Once regional sales are calculated as above, attribution of water consumption as a share of industry revenue are calculated to as a proportional share of water consumption by fiscal year, by country and by industry:

$$Water\ consumption\ ratio\ by\ regional\ allocation_{i,j,t} = \left(\frac{Sales\ by\ Region\ _{i,j,t}}{Exiobase\ Country - Industry\ Total\ Revenue\ _{j,t}}\right) \tag{6}$$

Finally, a water consumption imputation is calculated as the product of the total water consumed within a country-industry classification and the firm's water consumption ratio calculated as the quotient of sales by region and total country-industry revenue. Environmental impact of water is calculated is as equation 2.

$$Environmental\ Impact\ of\ Water_{i,j,t}\ Imputed\ = \sum\left(\begin{array}{r} Total\ Water\ Consumed\ (Exiobase)\ _{i,t} \times \\ Water\ Consumption\ Ratio\ _{i,j,t} \times \\ AWARE\ metric_j \times \\ Water\ Production\ and\ Delivery\ Cost_j \end{array}\right) + \left(\begin{array}{r} Total\ Water\ Consumed\ (Exiobase)_{i,t} \times \\ Sales\ by\ Region\ _{j,i,t} \times \\ Waterwaste\ Treatment\ Cost_j \end{array}\right) \tag{7}$$



Corporate Water Cost

Air Emissions

Applies WHO "Guidelines for drinking water quality"

Drinking and Irrigation Water Production Capacity

Production capacity value loss: emptying stocks of fossil water, decreasing precipitation or evaporation or changing water flows due to heat stress or pollution

Climate Change

Land Use

Water Pollution

CO_2

NO_x

SO_x

VOCs

$PM_{2.5}$

Each kg of emissions has a specific -m^3 reduction through damage to water production capacity

Market prices for drinking water are available from The International Water Association. Price is equity adjusted median value for 28 countries using country specific GDP with OECD average as reference. Note: for water, there is no global trade, local prices vary, resulting in a relatively high variability.

Water Consumption

Average Global Water Index
Water Production + Delivery + Treatment Cost

Waterfund Global Water Price

+

AWARE Water Scarcity Risk

National Metrics

213 national metrics + 17 global regions. Localization by nation of domicile or multiple countries of operation if percent of work force, or percent of emissions by nation disaggregated data is available.

Sub-national Metrics

+3400 administrative regions localized by watershed source. Localization by lat/long facilities of operation if percent of workforce, or percent of emissions by facility disaggregated data is available.

Figure 23 | Corporate Water Cost

Corporate Water Cost Monetization Methodology

Water cost + availability varies significant by region and is not easily portable; water use must be localized to regions of operations.

① **Waterfund's Global Water Cost Index** provides global prices for water production, delivery and treatment costs by region

② **WULCA's AWARE Model** provides water risk scarcity localization metrics to scale costs to global equivalent units.

$i = firm, t = year, j = country$

🟩 Corporate Disclosure

⬜ Waterfund's Global Water Price

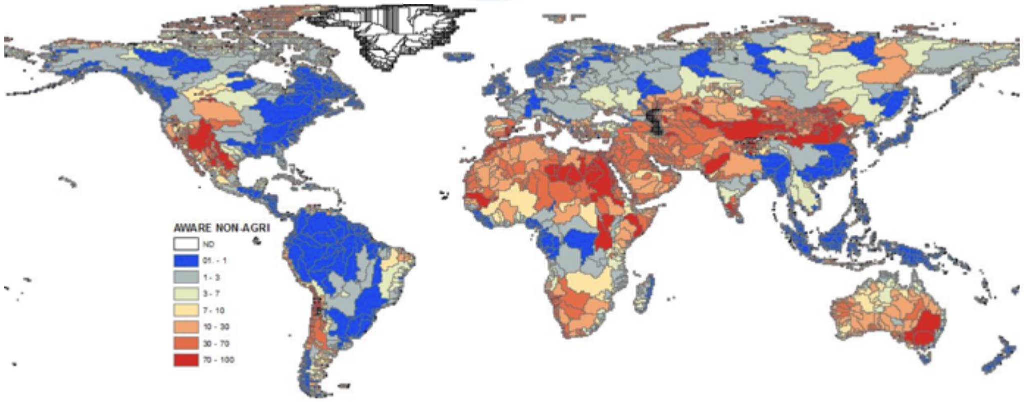
🟦 WULCA's AWARE Metrics

$$Total\ Environmental\ Impact\ of\ Water_{i,t,j}$$

$$= \sum \begin{array}{l} \left(\boxed{Net\ Water\ Consumed_{i,t}} \times \boxed{Water\ Production\ \&\ Delivery\ Unit\ Cost_j} \times \boxed{AWARE\ Water\ Risk\ Metric_{j,t}} \right) + \\ \left(\boxed{Net\ Water\ Consumed_{i,t}} \times \boxed{Wastewater\ Treatment\ Unit\ Cost_j} \right) \end{array}$$

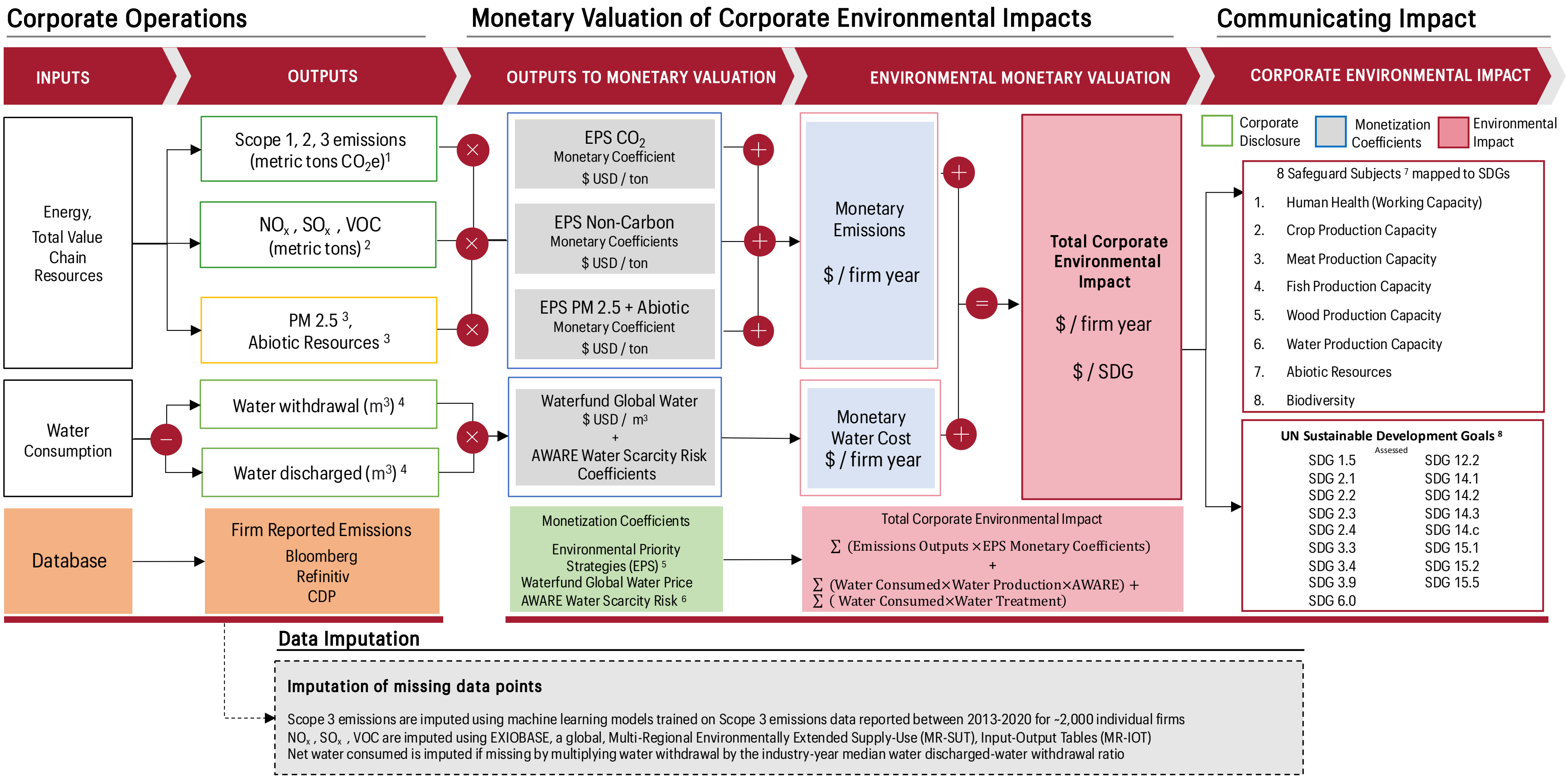
waterfund + WULCA = **Corporate Water Cost**

Waterfund + IBM developed Rickards Real Cost Water Index™ (WCI) to benchmark the true cost of water production in individual geographic areas, which includes operating, capital, and "hidden economic" cost



WULCA's AWARE water model indicates the relative water remaining in a given area using Availability Minus Demand (AMD) of humans + ecosystems and normalized with the world average. Represents relative value in comparison to world average.

Figure 24 |Corporate Water Cost Methodology Summary



Corporate Operations

Monetary Valuation of Corporate Environmental Impacts

Communicating Impact

INPUTS → OUTPUTS → OUTPUTS TO MONETARY VALUATION → ENVIRONMENTAL MONETARY VALUATION → CORPORATE ENVIRONMENTAL IMPACT

☐ Corporate Disclosure ▨ Monetization Coefficients 🟥 Environmental Impact

Energy, Total Value Chain Resources

Scope 1, 2, 3 emissions (metric tons CO_2e)[1]

NO_x, SO_x, VOC (metric tons)[2]

PM 2.5[3], Abiotic Resources[3]

EPS CO_2 Monetary Coefficient $ USD / ton

EPS Non-Carbon Monetary Coefficients $ USD / ton

EPS PM 2.5 + Abiotic Monetary Coefficient $ USD / ton

Monetary Emissions $ / firm year

Water Consumption

Water withdrawal (m^3)[4]

Water discharged (m^3)[4]

Waterfund Global Water $ USD / m^3 + AWARE Water Scarcity Risk Coefficients

Monetary Water Cost $ / firm year

Total Corporate Environmental Impact

$ / firm year

$ / SDG

8 Safeguard Subjects[7] mapped to SDGs

1. Human Health (Working Capacity)
2. Crop Production Capacity
3. Meat Production Capacity
4. Fish Production Capacity
5. Wood Production Capacity
6. Water Production Capacity
7. Abiotic Resources
8. Biodiversity

UN Sustainable Development Goals[8] Assessed

SDG 1.5	SDG 12.2
SDG 2.1	SDG 14.1
SDG 2.2	SDG 14.2
SDG 2.3	SDG 14.3
SDG 2.4	SDG 14.c
SDG 3.3	SDG 15.1
SDG 3.4	SDG 15.2
SDG 3.9	SDG 15.5
SDG 6.0	

Database

Firm Reported Emissions
Bloomberg
Refinitiv
CDP

Monetization Coefficients
Environmental Priority Strategies (EPS)[5]
Waterfund Global Water Price
AWARE Water Scarcity Risk[6]

Total Corporate Environmental Impact

$$\sum (\text{Emissions Outputs} \times \text{EPS Monetary Coefficients})$$
$$+$$
$$\sum (\text{Water Consumed} \times \text{Water Production} \times \text{AWARE}) +$$
$$\sum (\text{Water Consumed} \times \text{Water Treatment})$$

Data Imputation

Imputation of missing data points

Scope 3 emissions are imputed using machine learning models trained on Scope 3 emissions data reported between 2013-2020 for ~2,000 individual firms
NO_x, SO_x, VOC are imputed using EXIOBASE, a global, Multi-Regional Environmentally Extended Supply-Use (MR-SUT), Input-Output Tables (MR-IOT)
Net water consumed is imputed if missing by multiplying water withdrawal by the industry-year median water discharged-water withdrawal ratio

[1] Scope 1 and 2 are priority data collected by firm year; [2] Scope 3 emissions, non-carbon emissions and water consumption are imputed as detailed above; [3] PM 2.5 and abiotic resources are not collected through corporate disclosure, they are only assessed via EXIOBASE; [4] Water consumption costs vary by geographies and utility costs; water may be assessed at the nation of domicile level or at the sub-national facilities of operations level if disaggregated data is available. [5] EPS impact assessment method applies a Life Cycle Assessment (LCA) analysis to emissions + use of natural resources expressed as ELU (Environmental Load Units) and quantified as an externality corresponding to monetary damage cost. [6] Waterfund Global Water Index benchmarks the cost of water production in geographies and includes operating, capital, and "hidden economic" costs. The AWARE water model developed by WULCA create water scarcity risk localization metrics to calculate available water remaining per unit of surface in a given watershed relative to the world average after human and aquatic ecosystem demands have been met. [7] EPS defines the 8 Safeguard Subjects are environmental goods that have an economic value which is measured by their quality; a decrease of their quality is measured by the cost of restoring or preserving their quality. [8] The UN Sustainable Development Goals (SDGs) are a collection of 17 interlinked global goals designed to achieve a more sustainable future by 2030.

Figure 25 | IWA Corporate Environmental Impact Summary

Valuation Tool

The Corporate Environmental Impact Valuation Tool is a resource for industry practitioners to analyze corporate operations through an environmental impact lens. The Valuation Tool transforms the IWA methodology into an easy-to-use input-output system that calculates Corporate Environmental Impact valuation by firm year. The Valuation Tool produces scalable and comparable quantitative estimations of a corporate's exposure to environment externalities. The valuation tool is easily applicable to a portfolio context and equally in the evaluation of individual firm performance. The valuation tool is the first step in producing impact weighted accounts. Impact weighted accounts are line items on a financial statement, such as an income statement or a balance sheet, which are added to supplement the statement of financial health and performance. These additional line items are intended to help reflect a company's positive and negative impacts on employees, customers, the environment, and the broader society.

The valuation tool has required, non-required, and strictly imputed data as denoted in Table 4.

Table 4 | Valuation Tool Data Inputs

Required	Non-Required (Imputation Available)	Imputed Only
Scope 1 , 2 Emissions	NO_x	Abiotic Resources by Sector
Nation of Domicile	SO_x	PM 2.5
GICS Sub-Industry	VOC	NMVOC
Water Withdrawal *	Water Discharged	Miscellaneous (HOC)
Net Revenue		

** Water consumption imputation is available for select industries as noted in* Figure *22*.

The IWA research team draws emissions data as specified in Table *2*. The primary databases used are the Bloomberg ESG Index and the Refinitiv Asset4 [31] financial databases. For a large-scale analysis, these are the recommended databases to find the necessary metrics that the methodology requires. Any database the user has access to which contains the required metrics is suitable. If analyzing a smaller set of firms and primary data is not within financial databases, a secondary method would be to search for the firm's annual performance report or sustainability report. Please note that this is a costly and time-consuming process and only recommended in the case of an equity research report.

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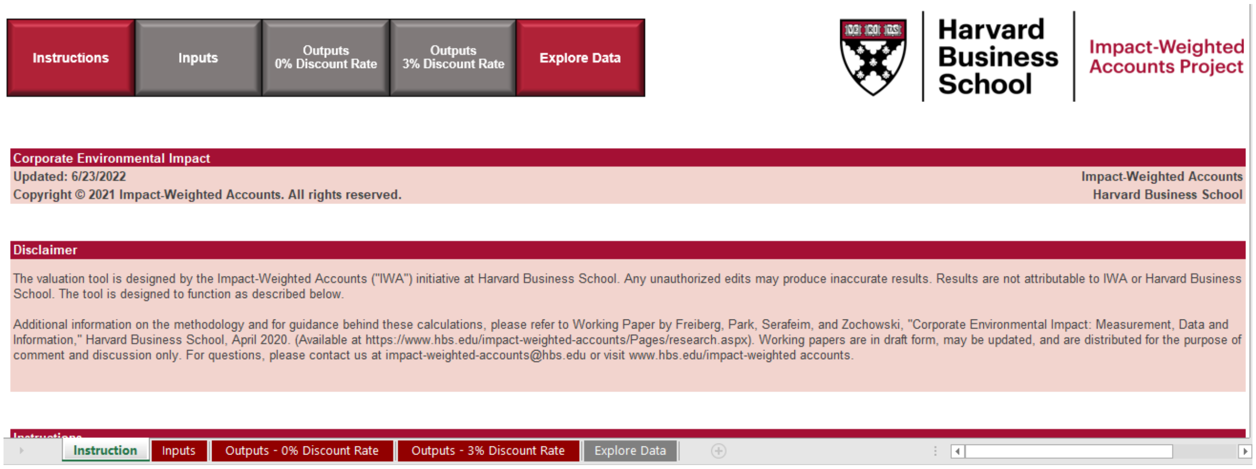
[31] Bloomberg. ESG Content and Data.
Refinitiv. Asset4 ESG Professional Guide.

Corporate Environmental Impact valuations are sensitive to firm specific factors and operations. Due to this, data imputations increase the variability of the valuations and increase uncertainty. Users should strive to draw required data from primary sources. Firm reported values and calculations should be used whenever available.

The IWA Corporate Environmental Impact Tool V1 is available for download on our research page. Please visit our website for future versions of the tool.



Corporate Environmental Impact

Updated: 6/23/2022 — Impact-Weighted Accounts

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Disclaimer

The valuation tool is designed by the Impact-Weighted Accounts ("IWA") initiative at Harvard Business School. Any unauthorized edits may produce inaccurate results. Results are not attributable to IWA or Harvard Business School. The tool is designed to function as described below.

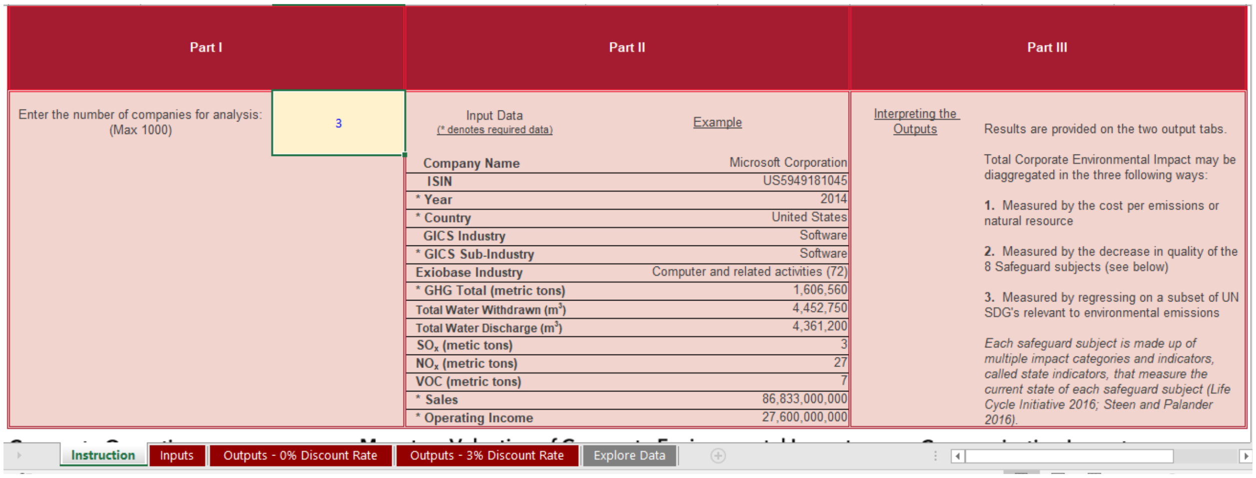
Additional information on the methodology and for guidance behind these calculations, please refer to Working Paper by Freiberg, Park, Serafeim, and Zochowski, "Corporate Environmental Impact: Measurement, Data and Information," Harvard Business School, April 2020. (Available at https://www.hbs.edu/impact-weighted-accounts/Pages/research.aspx). Working papers are in draft form, may be updated, and are distributed for the purpose of comment and discussion only. For questions, please contact us at impact-weighted-accounts@hbs.edu or visit www.hbs.edu/impact-weighted accounts.

There are five labeled sheets within the Valuation Tool. The following will provide an application of each sheet by showing proper use.

Data Inputs

Sheet 1: Introduction

1. To begin, please enter number of firms to be analyzed in Part I box on the introduction sheet. This can range from a single firm year to a portfolio to an index. Maximum observations is 1000.



Part I

Enter the number of companies for analysis: (Max 1000) 3

Part II

Input Data (* denotes required data)	Example
Company Name	Microsoft Corporation
ISIN	US5949181045
* Year	2014
* Country	United States
GICS Industry	Software
* GICS Sub-Industry	Software
Exiobase Industry	Computer and related activities (72)
* GHG Total (metric tons)	1,606,560
Total Water Withdrawn (m^3)	4,452,750
Total Water Discharge (m^3)	4,361,200
SO_x (metic tons)	3
NO_x (metric tons)	27
VOC (metric tons)	7
* Sales	86,833,000,000
* Operating Income	27,600,000,000

Part III

Interpreting the Outputs

Results are provided on the two output tabs.

Total Corporate Environmental Impact may be diaggregated in the three following ways:

1. Measured by the cost per emissions or natural resource

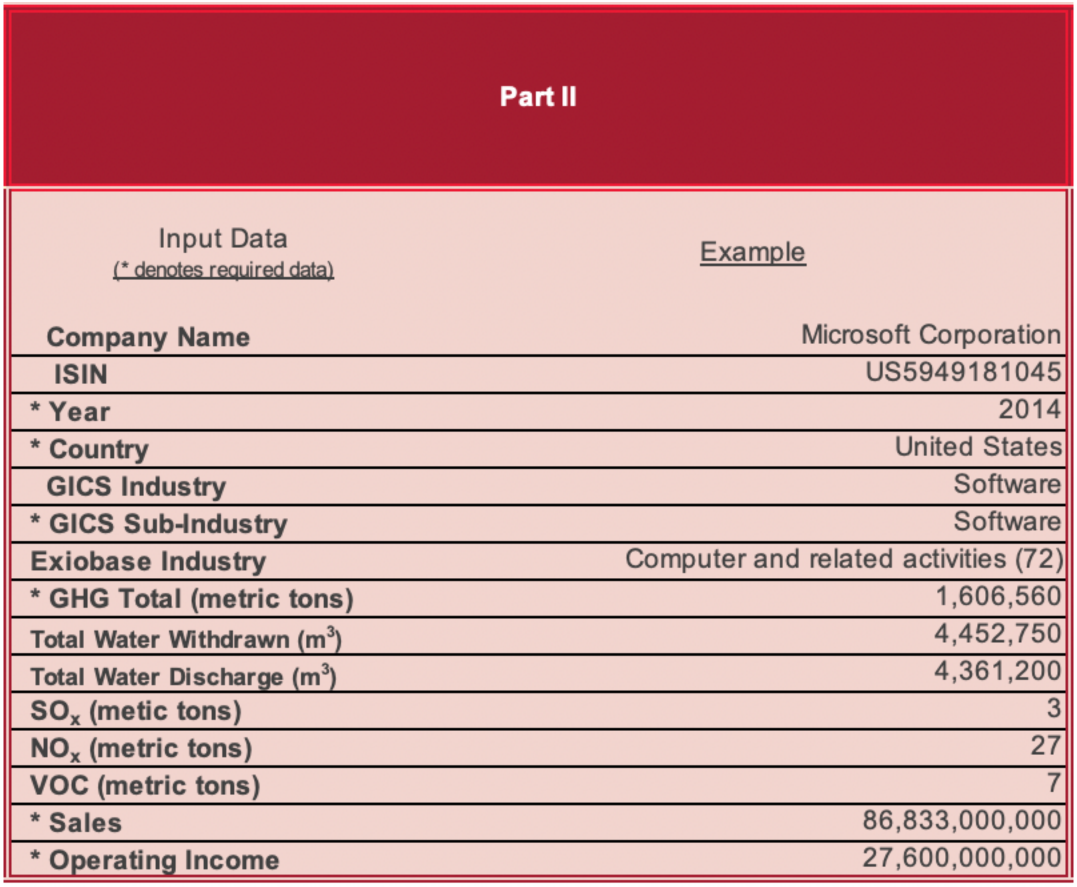
2. Measured by the decrease in quality of the 8 Safeguard subjects (see below)

3. Measured by regressing on a subset of UN SDG's relevant to environmental emissions

Each safeguard subject is made up of multiple impact categories and indicators, called state indicators, that measure the current state of each safeguard subject (Life Cycle Initiative 2016; Steen and Palander 2016).

2. Please review the required data (* denotes required data) in the Part II box. Please take note of the units required for input data. Emissions data must be input as metric tons and water data must be input as cubic meters. Please ensure correct units when drawing data from databases.

3. Sample Input



Part II

Input Data (* denotes required data)	Example
Company Name	Microsoft Corporation
ISIN	US5949181045
* Year	2014
* Country	United States
GICS Industry	Software
* GICS Sub-Industry	Software
Exiobase Industry	Computer and related activities (72)
* GHG Total (metric tons)	1,606,560
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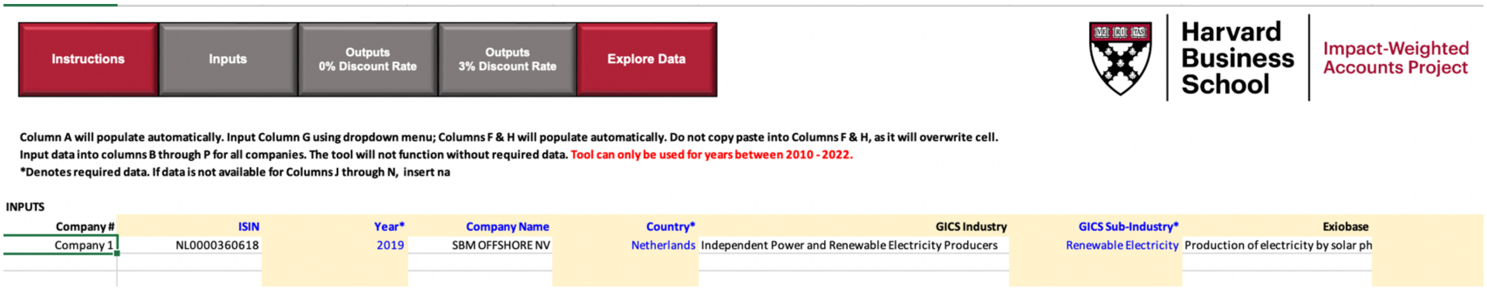
Total Water Discharge (m^3)	4,361,200
SO_x (metic tons)	3
NO_x (metric tons)	27
VOC (metric tons)	7
* Sales	86,833,000,000
* Operating Income	27,600,000,000

4. Navigating the Valuation Tool and Input Fields

Sheet 2: Inputs

After following the steps above and reading through the 'Instructions' tab, the 'Inputs' tab contains the cells where the required inputs are to be entered. There are 15 input cells. 6 cells are required inputs and highlighted in blue. If a cell located between Columns I through P is not required and data is not available, an entry of na is required input.

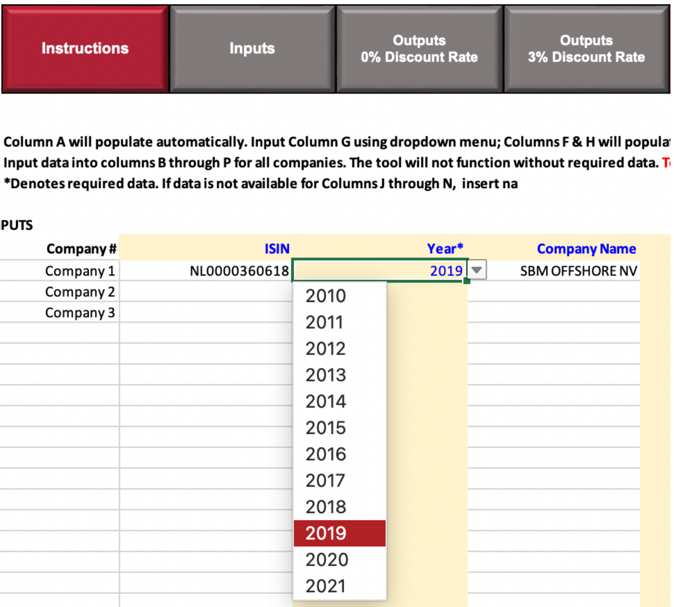


Column A will populate automatically. Input Column G using dropdown menu; Columns F & H will populate automatically. Do not copy paste into Columns F & H, as it will overwrite cell.
Input data into columns B through P for all companies. The tool will not function without required data. Tool can only be used for years between 2010 - 2022.
*Denotes required data. If data is not available for Columns J through N, insert na

INPUTS

Company #	ISIN	Year*	Company Name	Country*	GICS Industry	GICS Sub-Industry*	Exiobase
Company 1	NL0000360618	2019	SBM OFFSHORE NV	Netherlands	Independent Power and Renewable Electricity Producers	Renewable Electricity	Production of electricity by solar ph

5. Company specific inputs
    - **Company #:** this column will auto populate based on the entry on the 'Instructions' sheet.
    - **ISIN:** An International Securities Identification Number (ISIN) uniquely identifies a tradable security or financial asset. Not all firms have ISINs and this is not a required field. Column can be left blank/empty.
    - **Fiscal Year:** The Valuation Tool will only produce outputs fiscal years between 2010 - 2022. Ensure that the fiscal year being measured is between 2010 to 2022.
    - **Company Name:** Not a required input, can be left blank/empty.

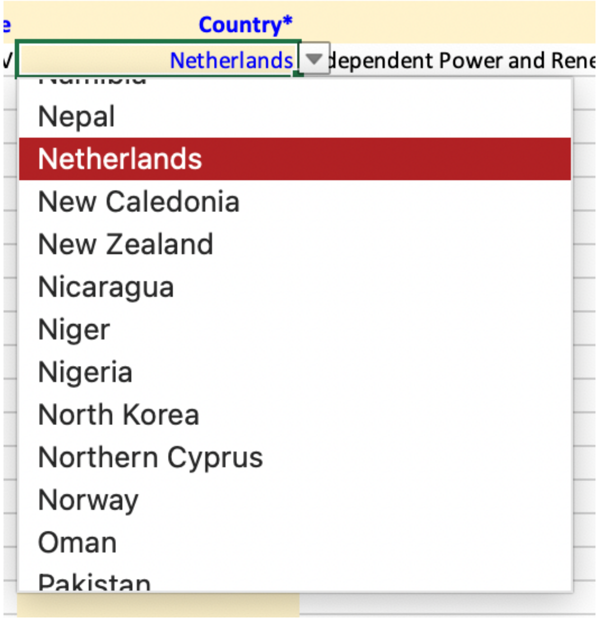


Column A will populate automatically. Input Column G using dropdown menu; Columns F & H will popula
Input data into columns B through P for all companies. The tool will not function without required data. T
*Denotes required data. If data is not available for Columns J through N, insert na

INPUTS

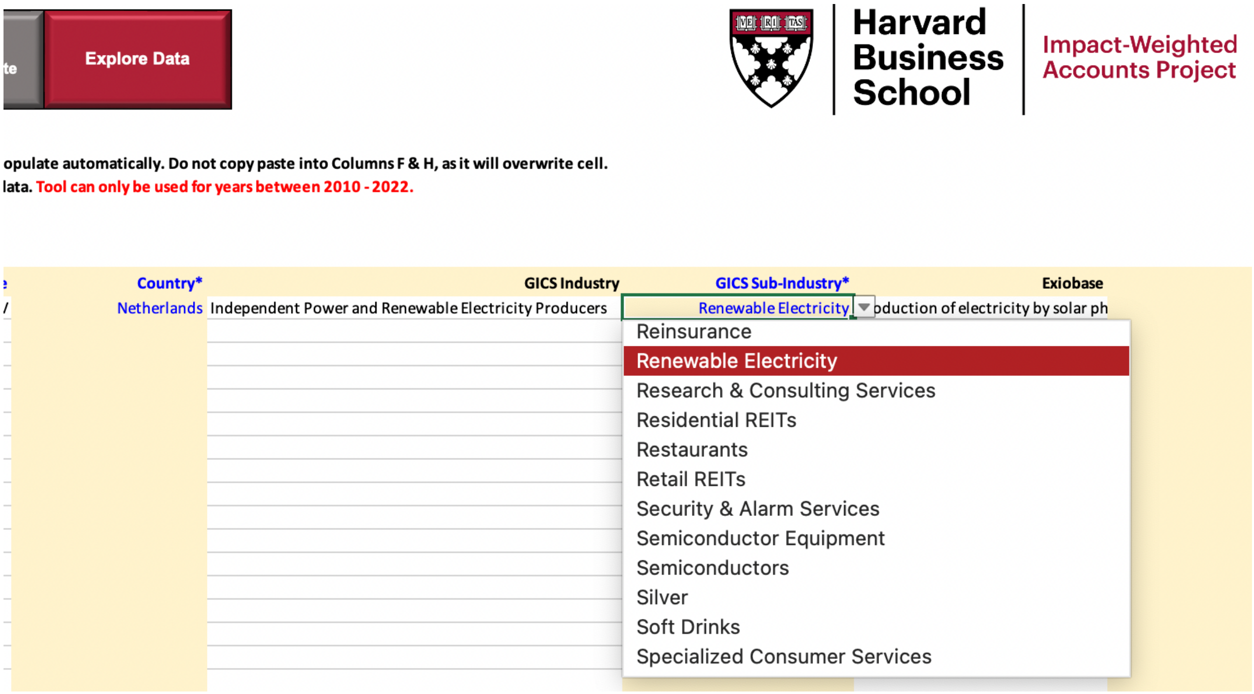
Company #	ISIN	Year*	Company Name
Company 1	NL0000360618	2019	SBM OFFSHORE NV
Company 2			
Company 3			

6. Geographic Data
    - **Country *:** This is a required input and must be selected from the dropdown menu. The Valuation Tool will not produce a valuation if this field is not entered in the correct format.



Country*	
Netherlands	dependent Power and Rene

7. Industry Classification Data
    - **GICS Industry:** This is not a required input; the field will auto populate once GICS Sub-Industry is selected from the drop-down menu.
    - **GICS Sub-Industry *:** This is a required input and must be selected from the dropdown menu. The Valuation Tool will not produce a valuation if this field is not entered in the correct format. Once GICS Sub-Industry is selected, GICS Industry and Exiobase will auto populate.
    - **Exiobase:** This is not a required input; the field will auto populate once GICS Sub-Industry is selected from the drop-down menu.

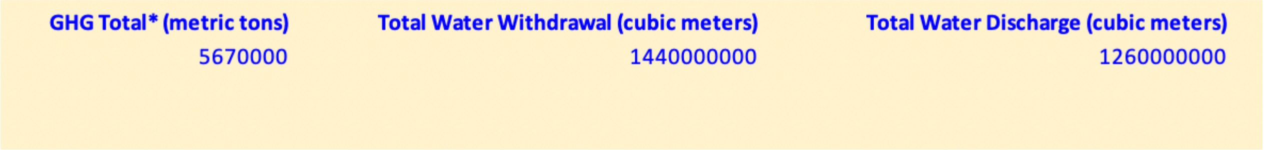


opulate automatically. Do not copy paste into Columns F & H, as it will overwrite cell.
lata. Tool can only be used for years between 2010 - 2022.

Country*	GICS Industry	GICS Sub-Industry*	Exiobase
Netherlands	Independent Power and Renewable Electricity Producers	Renewable Electricity	oduction of electricity by solar ph

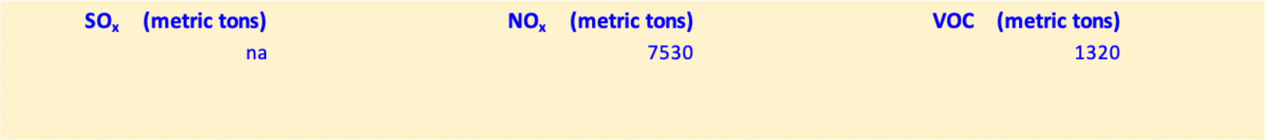
8. Emissions Data: ensure all units are entered as specified in the column header

** Water consumption imputation is available for select industries as noted in* Figure 22*.*
Otherwise, Total Water Withdrawal and Total Water Discharge is required input.



GHG Total* (metric tons)	Total Water Withdrawal (cubic meters)	Total Water Discharge (cubic meters)
5670000	1440000000	1260000000

If non-required inputs not available, please enter na as shown below. Do not leave empty nor blank.

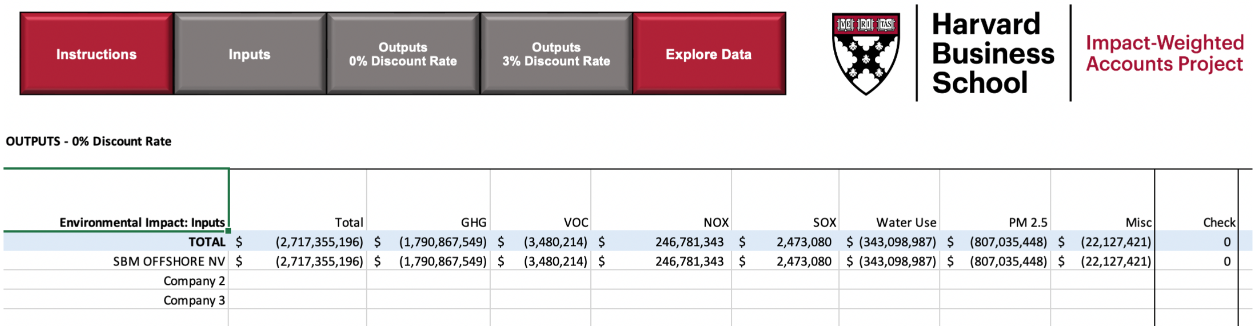


SO_x (metric tons)	NO_x (metric tons)	VOC (metric tons)
na	7530	1320

Valuation Outputs

9. Outputs 0% or 3% Discount Rate

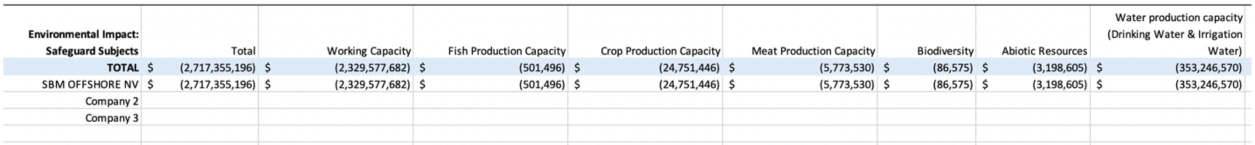
a. Attribution by emission type



OUTPUTS - 0% Discount Rate

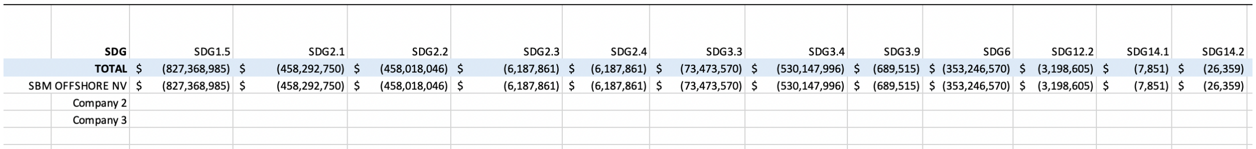
Environmental Impact: Inputs	Total	GHG	VOC	NOX	SOX	Water Use	PM 2.5	Misc	Check
TOTAL	$ (2,717,355,196)	$ (1,790,867,549)	$ (3,480,214)	$ 246,781,343	$ 2,473,080	$ (343,098,987)	$ (807,035,448)	$ (22,127,421)	0
SBM OFFSHORE NV	$ (2,717,355,196)	$ (1,790,867,549)	$ (3,480,214)	$ 246,781,343	$ 2,473,080	$ (343,098,987)	$ (807,035,448)	$ (22,127,421)	0
Company 2									
Company 3									

b. Attribution by Safeguard Subject



Environmental Impact: Safeguard Subjects	Total	Working Capacity	Fish Production Capacity	Crop Production Capacity	Meat Production Capacity	Biodiversity	Abiotic Resources	Water production capacity (Drinking Water & Irrigation Water)
TOTAL	$ (2,717,355,196)	$ (2,329,577,682)	$ (501,496)	$ (24,751,446)	$ (5,773,530)	$ (86,575)	$ (3,198,605)	$ (353,246,570)
SBM OFFSHORE NV	$ (2,717,355,196)	$ (2,329,577,682)	$ (501,496)	$ (24,751,446)	$ (5,773,530)	$ (86,575)	$ (3,198,605)	$ (353,246,570)
Company 2								
Company 3								

c. Attribution by UN SDG



SDG	SDG1.5	SDG2.1	SDG2.2	SDG2.3	SDG2.4	SDG3.3	SDG3.4	SDG3.9	SDG6	SDG12.2	SDG14.1	SDG14.2
TOTAL	$ (827,368,985)	$ (458,292,750)	$ (458,018,046)	$ (6,187,861)	$ (6,187,861)	$ (73,473,570)	$ (530,147,996)	$ (689,515)	$ (353,246,570)	$ (3,198,605)	$ (7,851)	$ (26,359)
SBM OFFSHORE NV	$ (827,368,985)	$ (458,292,750)	$ (458,018,046)	$ (6,187,861)	$ (6,187,861)	$ (73,473,570)	$ (530,147,996)	$ (689,515)	$ (353,246,570)	$ (3,198,605)	$ (7,851)	$ (26,359)
Company 2												
Company 3												

Communicating Environmental Impact

Total Corporate Environmental Impact

Communicating Impact

Monetary impact measurement facilitates the comparison, and integration of environmental performance into a firm's financial decision-making process allowing for quantitative management of risk, return, and impact, as well as more efficient, sustainable allocation of resources.

Monetary impact can be disaggregated into the following: environmental intensity, by emissions, by environmental goods or by UN SDG's in a manner that is transparent such that performance can be benchmarked and assessed across the market and within industrial classifications.

	Communicating Impact	Definition	Contextualizing Cost
1	**Environmental Intensity**	Sum of monetized emissions as percentage of profits **Intensity %** $= \sum \frac{Corporate\ \ Environmental\ \ Impact}{Corporate\ \ Profits}$	Total sum of monetized impacts divided by net revenue. Facilitates comparison across companies and industries in portfolio by normalizing size of company by revenue.
2	**Emissions and Resources**	Disaggregatedby the cost of each emissions + resource **Carbon emissions: Scope 1, 2, 3** **NO$_x$** **SO$_x$** **VOCs** **PM$_{2.5}$** **Water**	Identifies the main driver of overall impact valuation and allows for a risk, return, impact measurement along the metrics most relevant/accessible to investors.
3	**Safeguard Subjects**	Disaggregated by 8 Safeguards critical to economic production **Human Health** **Crop, Meat, Fish** **Wood** **Water** **Biodiversity** **Abiotic Resources**	Identifies the environmental goods and stakeholders most impacted by corporate operations. Facilitates management of impact by connecting operations to physical outcomes on humans and natural resources.
4	**UN Sustainable Development Goals**	Disaggregated by UN SDG's critical to the environment **SDG 1, 2 : No Poverty, Zero Hunger** **SDG 3: Good Health and Well-Being** **SDG 6: Clean Water and Sanitation** **SDG 12: Responsible Consumption** **SDG 14: Climate Action** **SDG 15: Life on Land**	Impact pathways + safeguard subjects emissions' impacts are mapped to United Nations Sustainable Development Goals (SDGs) most relevant to the environment.

Figure 26 | Communicating Impact across Valuation Tool outputs

There are numerous ethical and transparency considerations in reporting monetized impact. A leading goal of IWA's work has been to increase transparency for stakeholders affected by an organizations' activities and decisions. This requires, among other things, that netting be managed, documentation of assumptions, data sources and imputations, and clear display of impacts experienced by different stakeholders. Impact-Weighted Accounts Project at Harvard Business School has supported the Impact Economy Foundation in producing the Impact-Weighted Accounts Framework, which has gone through several rounds of public consultation and provides very specific guidance about managing these issues. This framework can be found at: https://impacteconomyfoundation.org/impactweightedaccountsframework/

Optimizing Environmental Impact

Impact Valuation of Equity-Weighted Portfolios

1. Weighted Average Carbon Intensity

TCFD Endorsed 2017

The weighted average carbon intensity (WACI) of a portfolio identifies the main drivers of a portfolio's climate risk exposure by measuring the impact of carbon-intensive companies. In light of regulatory pressures, carbon border adjustment taxes and carbon tax or cap and trade schemes, corporate exposure to carbon regulatory risks is growing. WACI concisely indicates a portfolio's potential exposure to transition risks relative to benchmark portfolios.

The WACI calculation is performed using the IWA methodology by combining Scope 1, 2, 3 carbon emissions and allocating based on portfolio weights (current value of the investment relative to current portfolio value).

Portfolio decomposition and attribution analysis; the IWA methodology allows these calculations to be easily made using attribution by resource consumption.

$$Carbon\ Emissions\ Intensity\ = \frac{GHG\ Emissions}{Net\ Revenue}$$

$$WACI\ = \textstyle\sum_{n\ =0}^{i} \left(\frac{current\ value\ of\ holdings\ _i}{current\ portfolio\ value\ _i} \times\ Carbon\ Emissions\ Intensity \right) \qquad (8)$$

2. Total Carbon Emissions Exposure

TCFD Endorsed

The Total Carbon Emissions (TCE) metric employs an equity-share ownership by measuring a portfolio's carbon emissions allocated to the portfolio in absolute terms. Ownership quantity based on levels of capital invested (market cap or enterprise value) in an equity attribute the level of emissions allocation to each investment.

Portfolio decomposition and attribution analysis; the IWA methodology allows these calculations to be easily made using attribution by resource consumption.

$$TCE\ = \sum_{n\ =0}^{i} \left(\frac{current\ value\ of\ holdings\ _i}{current\ portfolio\ value\ _i} \times\ Absolute\ Carbon\ Emissions\ \right) \qquad (9)$$

3. Carbon Emissions to Value Invested

The Carbon Emissions to Value Invested (CEVI) metric employs a normalized total carbon emissions by portfolio holdings. This allows comparison across portfolios with distinct strategies by normalizing across value invested to return. This metric demonstrates carbon intensity across and between portfolios.

$$CEVI = \frac{\sum_{n=0}^{i}\left(\frac{current\ value\ of\ holdings_{\ i}}{current\ portfolio\ value_{\ i}} \times Absolute\ Carbon\ Emissions\right)}{Portfolio\ Value} \qquad (10)$$

4. Carbon Emissions to Revenue Intensity

The Carbon Emissions to Revenue Intensity (CERI) performs a similar function to the Carbon Emissions to Value Invested metric but, in addition, it normalizes the Total Carbon Emissions by the issuer's revenues to enable comparison across portfolios of different sizes. [32]

The revenues approach allows for a better indication of output efficiency as revenues are a good proxy for production. For example, if an investor owns 1% of a company, they also own 1% of its emissions and 1% of its revenues.

$$CERI = \frac{\sum_{n=0}^{i}\left(\frac{Current\ value\ of\ holdings_{\ i}}{Current\ portfolio\ value_{\ i}} \times Absolute\ Carbon\ Emissions\right)}{\sum_{n=0}^{i}\left(\frac{Current\ value\ of\ holdings_{\ i}}{Issuer's\ market\ capitlization_{i}} \times Issuer's\ Net\ Revenue\right)} \qquad (11)$$

Summary

Table 5 | Portfolio Decomposition and Attribution Analysis

Metric	Units	Ownership	Methodology
Weighted Average Carbon Intensity	Metric tons CO2e/million revenues	No	The weighted average of corporate carbon intensity
Total Carbon Emissions	Metric tons CO2e	Yes	The aggregated apportioned carbon emissions of the portfolio constituents
Carbon Emissions to Value Invested	Metric tons CO2e/million revenues	Yes	The aggregation of apportioned carbon emissions of constituents per $ invested
Carbon Emissions to Revenue Intensity	Metric tons CO2e/million revenues	Yes	The aggregation of apportioned carbon emissions of constituents per $ generated in apportioned revenues

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[32] State Street Global Advisors. Environmental, Social and Governance.

Appendix

Air Emissions

Financially Material Greenhouse Gas Emissions

Greenhouse Gases

Greenhouse gases such as CO_2, CH_4, N_2O, and ozone, O_3, contribute to climate change by driving an increase in average ambient temperature on a global scale.[33] Their impact is attributed using global parameters as well as global costs per kg of emission.

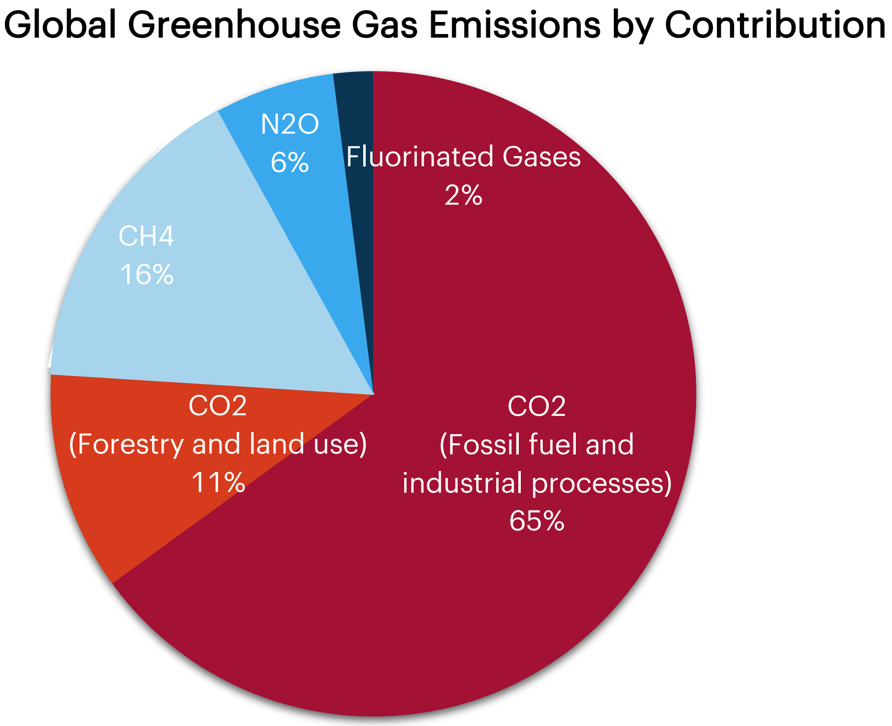

Figure 27 | Global Greenhouse Gas Emissions[34]

CO_2 | (GWP 100: 1)

Carbon dioxide emissions are the primary driver of climate change and contribute in the largest proportion to global greenhouse gases[35]. Consecutive IPCC assessment cycles have identified the critical need to reduce global CO_2 emissions if the worst effects of climate change are to be avoided. The majority of carbon dioxide emissions are created through the combustion of fossil fuels, industrial processes and biological respiration. CO_2 has a long residence time in air and is distributed throughout the atmosphere through large-scale atmospheric circulation, therefore, location and time of emissions on the globe are not relevant in the valuation the impacts of CO_2 emissions. CO_2 emissions impacts are valued globally in the year 2015 at any source strength.

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[33] EPA (2022). Global Greenhouse Gas Emissions Data.
[34] IPCC (2014). Fifth Assessment Report of the Intergovernmental Panel on Climate Change
[35] EPA (2022). Global Greenhouse Gas Emissions Data.

Air Pollutant Emissions

Air pollutant emissions contribute to climate change by decreasing the air quality through chemical interactions at the regional level. Primary air pollutants react with atmospheric gases to produce deleterious secondary pollutants that increase air toxicity. Air pollutant emissions are relevant at the regional level and are imputed at the nation of operations level, when necessary, within the IWA methodology.

Financially material air pollutant emissions

NO$_x$ | (GWP 100: - 95 ± 31)

Nitrogen Oxides are mono- and di-nitrogen oxides which are toxic and highly reactive oxidizing agents produced when hydrocarbon fuel is burned. NO$_x$ pollution is produced as a byproduct of automobiles, transportation trucks, marine shipping vessels, air transport vehicles and construction equipment operation, as well as industrial sources such as power plants and industrial boilers. NO$_x$ reacts with VOCs to produce O$_3$ smog.[36] NO$_x$ emissions are market regulated.

SO$_x$ | (GWP 100: - 40)

Sulphur Oxides are primarily Sulphur dioxide with some Sulphur trioxide, which are toxic and highly reactive oxidizing agents produced when hydrocarbon or high Sulphur content fuel is burned at high temperatures. SO$_x$ pollution is produced as a byproduct of fossil fuel combustion at power plants and other industrial facilities. Smaller sources of SO$_x$ emissions include: industrial processes such as extracting metal from ore; natural sources such as volcanoes; marine transport vessels, other fuel burning vehicles.[37] SO$_x$ emissions are market regulated.

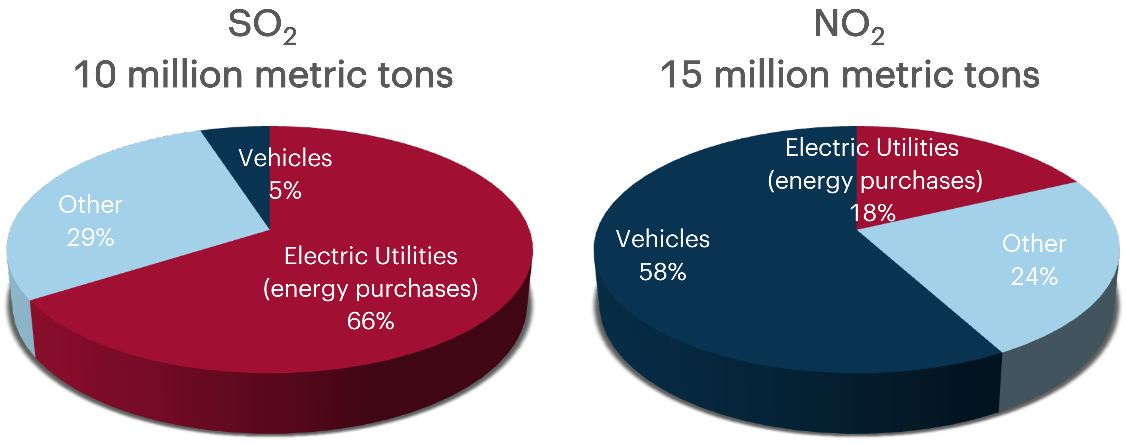

Figure 28 | Air Pollutant Emissions [38]

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[36] EPA (2022). Nitrogen Oxides (NOx) Control Regulations.
[37] EPA (2022). Sulfur Dioxides Basics.
[38] EPA (2020). National Emissions Inventory (NEI).

NO_x | SO_x: Climate impacts from secondary particles [39]

The largest impact and negative monetary cost (- $) of NO_x and SO_x emissions arise from their role in the production of secondary particle, such as $PM_{2.5}$ (excess mortality), and oxidizing agents such as O_3. More recently, the IPCC Assessment Report (AR 5), research determined that indirect reactions from NO_x and SO_x emissions can both increase or decrease global warming: e.g., NO_x emissions counteract global warming by creating nitrate particles which produce a cooling effect, and by decreasing methane concentration. Notwithstanding, there is still debate within the scientific community regarding the overall impacts of NO_x and SO_x emissions. For example, the negative radiative forcing from NO_x and SO_x is a recent discovery that first appeared in IPCC AR5. Although there is no global consensus within the scientific community about the overall impact, NO_x and SO_x are generally known to have a negative effect on radiative forcing. Negative radiative forcing would moderate the global warming effects caused by greenhouse gases and increase human working capacity. Due to the negative radiative forcing, excess mortality due to heat stress decreases and working capacity increases as a consequence. In this case, the benefits (excess mortality reduction due to global temperature abatement) of NO_x and SO_x are higher than the costs (excess mortality due to respiratory system exposure), so the net monetized impact of NO_x and SO_x positive (+ $). Despite the negative radiation forcing effects, global abatement measures are still of principal concern.

$PM_{2.5}$

Particulate matter of diameter 2.5 micrometers and smaller are fine inhalable particles produced directly through sources such as construction sites, smokestacks, or fires. The majority of $PM_{2.5}$ particles form in the atmosphere as a result of reactions with NO_x and SO_x. $PM_{2.5}$ is one of the highest risk factors for death around the world and contributes to excess mortality [40].

VOCs

Volatile organic compounds are gaseous industrial chemicals and solvents produced in the manufacturing of industrial and household products such as paints, adhesives, pharmaceuticals, cleaning supplies, cosmetics, and refrigerants. VOCs are often components of petroleum fuels, hydraulic fluids and are common ground-water contaminants. Concentration of VOCs are up to 10 times higher indoors than outdoors. VOCs are not acutely toxic, however, concentration levels and long-term exposure to VOCs may produce adverse health effects and some VOCs are suspected or proven carcinogens.[41] VOCs are market regulated.

NMVOC

Non-methane volatile organic compounds are identical to VOCs with the exclusion of methane, which is non-toxic in terms of air pollution. NMVOC is an O_3 precursor and produced through transportation, combustion activities, solvent use, and production processes. NMVOCs contribute to the formation of O_3 through reactions with NO_x and are a very potent GHG. [42] Market regulated.

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[40] Environmental Health Perspectives (2021). Morality Risk from $PM_{2.5}$.

[41] EPA (2022). Volatile Organic Compounds' Impact on Indoor Air Quality.

[42] Koppmann, R. Institute for Chemistry and Dynamics of the Geosphere (2007). Volatile Organic Compounds...

Current Developments in Data Imputations

Data Collection

Emissions

Bloomberg

Refinitiv

CDP

Financial

S&P Capital IQ

Data Cleaning

Remove firm's year over year outliers within defined boundaries. Cross-validate emissions across multiple databases.

Data Imputations

Machine learning models

EXIOBASE: Supply-Use Tables (MR-SUT/ IOT)

Data Sample Set

Scope 1, 2:

14,514 Firm-year observations

Scope 3:

9,014 Firm-year observations

Metric	**Imputation Limitations**	**Current Developments**
Scope 3	Small sample set of reported emissions across Scope 3. Low corporate disclosure results in increased machine learning prediction error.	Future machine learning models will continue to improve with increased reporting landscape
NO_x, SO_x, VOC $PM_{2.5}$, NMVOC Abiotic Resources	**EXIOBASE has industry mapping limitations that may lead to inaccuracies**: lack of precision at the geographic, and industry level reduces sector comparability. **Insufficient data for some EXIOBASE industries:** leads to 'zero' coefficients for select industries which returns zero values for imputations **Limited granularity for regions outside EU** (5 "Rest of World" regions). Increases error for companies that operate globally, and in developing countries. **Significant variation in industry tables across comparable countries:** reduces comparability	Assumption that emissions scale with sales, limitations with location of operations. Pro-rata portion of industry total is allocated to a firm by ratio of revenue to total industry output per firm year within a given geographic region. Machine learning model currently under development.
Water Withdrawal Water Discharged	**EXIOBASE water tables focus on limited industries** (e.g., agriculture, livestock, manufacturing). **Imputations based on firm domicile rather than facilities of operations:** Increases error in water cost, as coefficients vary significantly by country/industry with high water use/scarcity **Imputation not possible:** when water withdrawal is not reported	Geospatial localization of water use by facilities of operations is currently under development. Provides granular assessment of water scarcity risk and cost.

Increasing 'degree' of imputation