METHODOLOGICAL REPORT

WifOR Impact Valuation

Underlying valuation approach, assumptions, and extrapolation.

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Contents

1 Introduction to this publication

This document describes the methodology underlying WifOR's approach to impact valuation. WifOR, as an independent research institute, is committed to supporting efforts towards meaningful impact measurement of companies and sectors. In the absence of a freely available set of regionalized valuation coefficients for both environmental and social impacts, WifOR has developed a set of coefficients for a range of environmental and social indicators and recommends their usage until a global standard is made public. WifOR decided to publish the coefficients and the underlying methodology to promote transparency and as a consequence, public discussion about valuing non-financial impacts. As impact valuation seeks to make values of completely different impact areas comparable in monetary terms, this involves a number of ethical questions and strong need for standardisation.

Currently, several approaches towards impact valuation exist and partly differ considerably. The divergence of different monetization coefficients might cause the impression that results are arbitrary and non-reliable for strategic decision making. To counteract these concerns, a standardisation of impact valuation should be the long-term goal. However, such a standardisation involves decisions on valuation which cannot be done by a single institution alone and rather need to involve a broad set of stakeholders. Publication of coefficients and methodology is a step forward to increase stakeholder dialog and build trust in the methodology. It might be the case that there is no final agreement on the exact way how to conduct impact valuation as some ethical questions cannot be resolved. However, this is not a fundamental problem for the method as results can transparently be seen in light of the underlying ethical choices (a common example is the different valuation of GHG emissions depending on the valuation of future generations).

The authors are aware that progressing academic research and data availability will require further development of the valuation coefficients. Future changes to the valuation are unavoidable due to its innovative character and reflect the rapid development of impact valuation in general. Likewise, new valued indicators are constantly being developed and included in the WifOR valuation framework.

This document is structured as followed: Chapter 2 describes the general idea of impact valuation. Chapter 3 describes the methodology used by WifOR. Chapter 4 describes each indicator covered by the WifOR valuation framework in the environmental and social domain. Each indicator documentation is structured into an overview part, an impact pathway, the description of the valuation approach and some highlighted assumptions.

2 General methodology

2.1 Introduction to Impact Valuation

The societal and economic conditions for companies have changed fundamentally in recent years. Buzzwords such as resource-efficient growth, climate neutrality, fair prices, social standards, circular economy, and biodiversity conservation are shaping the agenda of policy and businesses alike. Among others, the design of the European Supply Chain Law is discussed vividly, with a consensus that collaborative corporate action is needed to sustain our planet. Therefore, it is important to recognise, understand and ultimately manage the multiple impacts economic actors have on society. Assessing and reporting on impacts is the first step to approach this challenge. Normally, the direct and indirect outputs of corporate activities are captured and reported in their quantification units, e.g., tones of greenhouse gases or the number of occupational accidents. Impact valuation goes two steps further: First, the environmental and social changes triggered by these outputs are recorded and their impacts on society traced. Second, these impacts are then translated into monetary values. Following this approach of harmonizing impacts to a common metric, the wide range of output indicators traditionally reported can be made comparable.

	Impact	x	Valuation coefficient	=	Monetized impact
Example GHG:	CO_2e in t	x	Societal costs per t CO_2e	=	Societal costs of CO_2 emissions

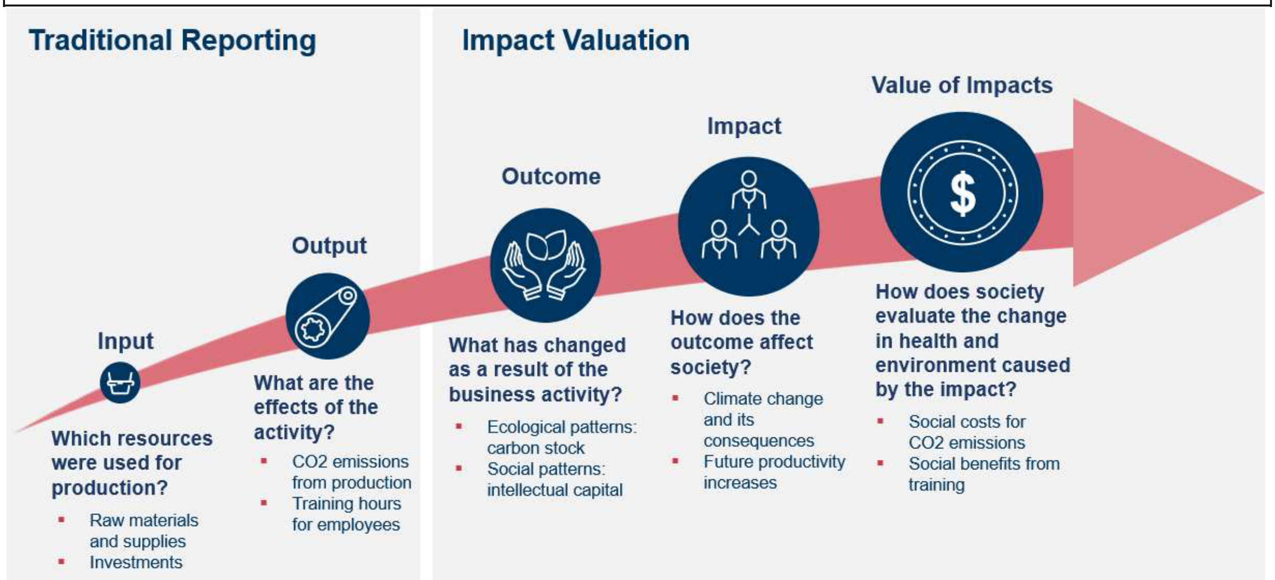

Figure 1: General approach to monetize impacts (adapted from VBA 2021[1])

It should be noted that valuation methods are partly based on normative decisions, including the handling of future damages (see 3.2) and the valuation of a human life in different countries (see 3.3) and can therefore never claim to be objective.

[1] Value Balancing Alliance e.V. (2021): Methodology Impact Statement General Paper Version 0.1. Consultation Draft, Feb. 2021.

2.2 Scope of application

The scope of impact drivers considered in this methodology spans the three common dimensions of sustainable business practice: economic, environmental, and social. A meaningful assessment of impact to society acknowledges that a company's influence on these three dimensions must go beyond the boundaries over which it exercises direct financial or operational control. By purchasing goods and services globally, companies have indirect impacts associated with the production of their purchases, directly at the supplier and further up the supply chain. Similarly, the design of products and services affects how customers use and dispose products, which again leads to indirect impacts on society.
This methodology aims to be applicable to the full value chain of an organization, namely:

Figure 2: Scope of impact valuation

3 What is being valued and how?

3.1 General valuation framework

There are two major perspectives on value: the stakeholder perspective that focuses on positive and negative impacts of corporate activities on the environment and society – the *value to society* perspective. And a financial-driven view of the consequences of these impacts (and dependencies) on the financial performance of corporations – the *value to business* perspective. Both perspectives are inherently connected and have, thus, been widely acknowledged as “double materiality”.[2,3,4] This methodology follows the *value to society* perspective and aims to reflect the impact that businesses have on their environment and society at large.

There are different approaches to measure *value to society*. Which one is chosen depends on the area of application and purpose of the conducted analysis. The two most prominent approaches are based on the estimation of (1) abatement costs and (2) damage cost. Abatement costs reflect the costs of avoiding specific impacts, e.g., conservation funds to prevent the decline of biodiversity. Damage costs reflect the costs of impacts that already happened. These are mostly cost of damages to human health, life quality, or economic losses. At WifOR, the valuation of each indicator is intended to reflect damage costs. This is not possible for all indicators as some impact pathways and their consequences to society and the environment are not yet sufficiently understood. Details on how specific indicators have been valued can be found in the respective documentations (see section 4).

Another aspect that is considered in the valuation framework is that the impact on society of impact driver depends on the local social and environmental settings in which they occur. To address this issue, country specific valuation coefficients have been developed for 188 countries. These local values reflect that, e.g., draining water resources have more serious health effects in locations of higher water scarcity. The adjustment of monetization coefficients across space is detailed in the respective indicator documentations (see section 4). Exception are greenhouse gas (GHG) emissions and marine plastic leakage. The impact of GHG emissions, namely climate change, occurs globally and irrespective of their release source. The value is hence universal. Further information about this specificity can be found in the GHG valuation documentation (see 4.1.1). A similar consideration is valid for marine plastic leakage (see 4.1.8).

3.2 The valuation of losses in the future

Many of the social and environmental effects manifest not only in the present, but also in the future. For a comprehensive assessment of the effects of corporate activities, these effects on future generations must be considered. In economics, discounting is commonly used to convert costs and benefits incurred in the future into their net present value.

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[2] Accountancy Europe (2020): Interconnected Standard Setting for Corporate Reporting https://www.accountancyeurope.eu/wp-content/uploads/191220-Future-of-Corporate-Reporting.pdf.

[3] CDSB (2020): Falling short? https://www.cdsb.net/sites/default/files/falling_short_report_double_page_spread.pdf.

[4] EU Commission (2019): Guidelines on reporting climate-related information https://ec.europa.eu/finance/docs/policy/190618-climate-related-information-reporting-guidelines_en.pdf; Natural Capital Protocol (2016), p.15.

Discounting can be motivated by the fact that (1) people tend to place more weight on the present than the future, (2) that consumption growth is expected in the long run, and thus a unit of wealth will be worth less in the future than it is today, and (3) that the benefit from additional consumption decreases as the level of consumption increases. These three aspects are reflected in the social discount rate (SDR), known as the Ramsey rule[5]

$$SDR = \gamma + \eta * g$$

where γ is the pure time preference rate, η is the elasticity of marginal utility of consumption and g is the growth rate of per capita consumption.

The social discount rate effectively limits how far into the future impacts are captured. For example, at a rate of 2%, impacts 50 years in the future have a present value of ~37%; at 1.5%, it is ~61%.

The value of the social discount rate and its components is the subject of intense scientific debate, particularly in the environmental economics literature on climate change. This method follows the approach of the German Federal Environment Agency[6], with the assumption of a long-term growth rate of g=1.5%[7] and η=1. The pure time discount rate reflects ethical choices about the value of future generations. While the consumption growth and marginal utility of consumption are already uncertain parameters, no objective value can be given for the pure time discount rate. There is a strong recommendation to value future generations equal to current generations which is in line with the notions of intergenerational equity prevalent in the climate change literature. The exceptions of this rule should be clearly labelled. If not otherwise stated, this results in a social discount rate of 1.5%.

[5] Ramsey, F. P. (1928). A mathematical theory of saving. The economic journal, 38(152), 543-559.

[6] Umweltbundesamt. (2012): Ökonomische Bewertung von Umweltschäden – Methodenkonvention 2.0 zur Schätzung von Umweltkosten. Dessau-Roßlau: Umweltbundesamt. https://www.umweltbundesamt.de/en/publikationen/oekonomische-bewertung-von-umweltschaeden-0.

[7] World Bank. (2022): Households and NPISHs Final consumption expenditure per capita growth (annual %) | Data. https://data.worldbank.org/indicator/NE.CON.PRVT.PC.KD.ZG (retrieved: 26. September 2022).

3.3 The valuation of human life

Can and should a monetary value be assigned to human life? And if so, how can the "value" of human life be determined? These questions are controversially debated inside and outside impact valuation research. Whenever human lives are affected by a decision, the options' impacts must be weighed against each other - implicitly, human lives are therein always given a value. In impact valuation, this value is made explicit, which enables and even requires a debate about this - essentially ethical - valuation.

There are two basic approaches to valuing human life. The productivity-based perspective values a life-year in terms of a person's productivity, i.e., the value of their paid and unpaid work. The willingness-to-pay perspective, on the other hand, determines the "Value of Statistical Life" (VSL), from which the "Value of a Statistical Life Year" (VSLY) is derived.

The VSL essentially reflects the willingness to pay to avoid death. The VSL approach is used, for example, in policy making to assess whether regulations to reduce the likelihood of death are worth the cost of implementing them. As this approach takes the perspective of the people affected, the WifOR valuation method applies a VSLY approach.

VSLY estimates depend on the country, the age of the population, the level of wealth, and the assessment method.[8] While WHO recommends a magnitude of 1-3 times the gross domestic product (GDP) per capita, several studies criticise this value based on empirical studies between 3.5 and 6.5 times the GDP per capita.[9,10] Schlanderer et al. (2017), for example, determine approximately six times the GDP per capita as the median value in a meta-analysis of over 120 VSLY studies between 1995 and 2015.

In this methodology, the same value is used for valuing effects on human lives across the world for ethical reasons. The VSLY is assumed to be four times the GDP per capita of a high-income country. Since an exact estimate of the VSLY cannot be determined, the value is rounded smoothly to 200,000 USD in order not to feign false accuracy. The chosen value is thus at the higher end of VSLY estimates.

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[8] Schlander M, Schaefer R, Schwarz O (2017): Empirical Studies On The Economic Value Of A Statistical Life Year (VSLY) In Europe: What Do They Tell US? VALUE IN HEALTH 20 (2017) A399–A811.

[9] Trautmann, S.T., Xu, Y., König-Kersting, C. Patenaude, B.N., Harling, G., Sié, A., Bärnigjausen, T. (2021): Value of statistical life year in extreme poverty: a randomized experiment of measurement methods in rural Burkina Faso. *Population Health Metrics*. https://doi.org/10.1186/s12963-021-00275-y.

[10] Robinson LA, Hammitt JK, Chang AY, Resch S. (2017): Understanding and improving the one- and three-times GDP per capita cost-effectiveness thresholds. Health Policy Plan. 2017; 32:141–5.

3.4 Standardization among indicators

An important aspect of generating meaningful and comparable results is to ensure a harmonized set of indicators. As described above, a consistent valuation approach (damage cost approach) has been chosen where possible. In addition to that, all coefficients are harmonized in the following aspects:

Time: All indicators are adjusted for inflation and currently reflect the year 2020. To do so, GDP deflator values from the World Bank are applied in the respective local currency. The values are afterwards converted to US dollars.

PPP adjustment: If an impact occurs locally and is directly affecting people, values are adjusted for purchasing-power-prices (PPP) to reflect local prices.

Social discount rate: For indicators that are subject to social discounting, a universal rate of 1.5% is applied across indicators. See section 3.2 for more information.

Valuation of human life: For indicators that include the loss of life years and loss of years in good health, a universal value for a year of life in good health is applied across indicators. The value is set to 200,000 USD/year. See section 3.3 for more information.

3.5 Double counting

Impact valuation entails the risk of double counting. That is because different impact drivers follow the same or similar impact pathways. The issue of double counting mostly arises when analysing several indicators at once. An example is that incinerating waste releases air pollution that in consequence is responsible for respiratory diseases that lead to health costs. These costs are embedded in the “waste” coefficient but are also integrated in the “air pollution” coefficient. Subtracting this impact from the waste coefficient would mean to not properly display the impact of waste, while adding the impact of the two indicator is subject to double counting. Caution should also be exercised with indicators that are available in different levels of granularity. One example consists in the air pollutants PM2.5 (particulate matter sized 2.5 micrometres in diameter or less) and PM10 (particulate matter sized 10 micrometres in diameter or less). Per definition, PM2.5 is part of PM10. The smaller particles however have a graver effect on human health and are hence assigned a higher cost and shown differentiated.

3.6 Netting impacts

Impact valuation aims to increase transparency, which it cannot fulfill if results are presented at a highly aggregated level. The benefits of expressing different impacts in a common metric reduces complexity but comes at the costs of cancelling out nuances. This can be helpful but should not imply that negative impacts can be offset with positive impacts. There are cases where netting impacts serves the purpose (e.g., netting an indicator across locations) while there are applications (e.g., netting across different indicators) that pose the risk of greenwashing and communicating distorted results. One reason is that in the current state of impact valuation, issues such as overlaps between indicators (double counting), different valuation approaches and a lack of data to fully picture impacts are still present. Beside that, different groups of people are affected by different impacts, meaning that a group of people facing negative impacts are not compensated by positive impact that affect a different group of people (e.g., extra vocational training for managers does not compensate for farming losses due to water shortage). The authors therefore advise for a separate designation of impact drivers and treat netting and the analysis of results with caution.

4 Indicator documentations

In this chapter we introduce the impact valuation approaches for each indicator. The chapter is divided into ecological and social domains. For each indicator, a small overview concerning the context of valuation is given. Thereafter, an impact pathway describing the underlying valuation concept. The third part contains the chosen approach for impact valuation and is accompanied by a subchapter on key assumptions.

4.1 Ecological indicators

4.1.1 Greenhouse gases

Overview

Emissions of greenhouse gases induce global warming by creating a greenhouse effect in the earth's atmosphere. Due to climate change, we will experience an increase in extreme weather events and rising sea levels, as well as a decrease in surface and ground water resources.[11] Greenhouse gases included in the analysis are the most contributing and dominating ones: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2). GHGs are accounted for according to their global warming potential (GWP), whereby CO_2 is taken as a baseline and the GWP of other gases is measured relative to the same mass of CO_2 (called CO_2 equivalents, short CO_2e). They are evaluated for a specific timescale, in this case a 100-year time horizon. The applied GWP factors are in line with the fifth assessment report of the intergovernmental panel on climate change (IPCC).

Costs arising from climate change are manifold. Following the recommendation of the German Environmental Agency (UBA), costs of climate change are assessed in terms of their damage.[12,13] These include lost benefits like the loss of agricultural yield, a reduction of recreational benefits or a reduction in the quality of life due to chronic health damages (see Figure 3). While economic losses (e.g., foregone revenue due to a lower yield) are already expressed in monetary terms, other impacts on society require a translation of damages into monetary terms ,e.g., health damages being expressed in medical treatment costs.

[11] IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[12] Matthey, A.; Bünger B. (2019): Methodenkonvention 3.0 zur Ermittlung von Umweltkosten: Kostensätze, Umweltbundesamt, Februar 2019, https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2018-11-2_methodenkonvention-3-0_methodische-grundlagen.pdf.

[13] Anthoff, D. (2007): Report on marginal external damage costs inventory of greenhouse gas emissions. Hamburg, Hamburg University: 47.

Impact Pathway

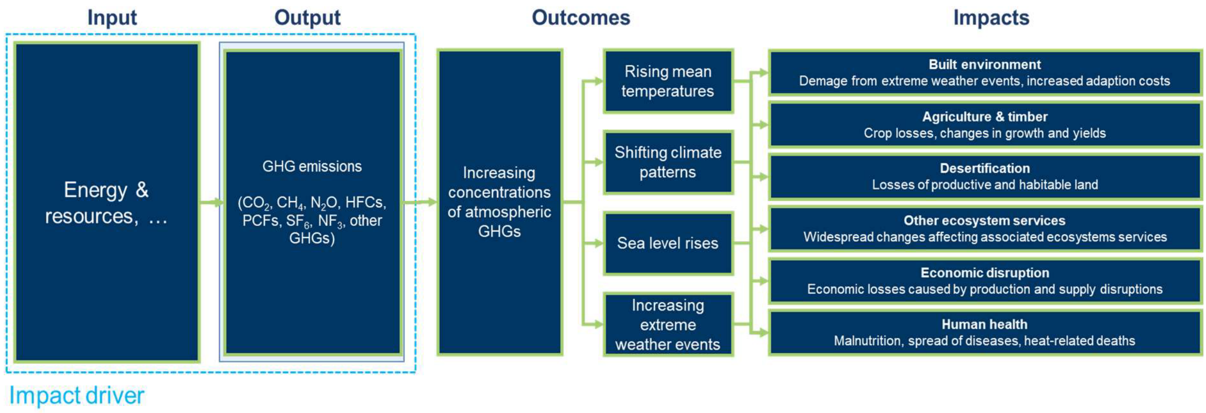

Figure 3: Impact Pathway of GHG emissions (source: own illustration)

Valuation approach

For the evaluation of GHG emissions, we apply the widely used concept of social costs of carbon (SCC).[14] The SCC measures the damage of one additional ton of GHG released to the atmosphere. Hereby, the damage of all future years is considered. The SCC is always calculated with respect to an assumed future emission trajectory. It is derived via so called integrated assessment models which combine economic modelling with climate models. Geophysical assumptions (like climate sensitivity of the GHG stock in the atmosphere) and economic assumptions, like future energy demand and abatement technologies influence the result. For the valuation of GHGs, no country specific valuation factors are necessary, as GHG emissions have a global impact on climate change. Their release location is not decisive for a local impact, as GHGs accumulate into stocks of GHGs in the atmosphere. The overall stocks of GHGs are what matter, and not their place of origin.[15] Therefore, the valuation coefficient is equal across all countries and industries.

Assumptions

When choosing the SCC as the valuation concept, it is crucial to be specific about the valuation of future generations. As mentioned in chapter 3.2, future impacts are discounted with the social discount rate. The SCC values are highly sensitive with respect to the discount rate and results should always be seen in the light of the underlying assumption. We follow the assumption of the UBA (Federal environmental agency of Germany) using a pure time discount rate of 1%. This results in an SCC of €180 per ton of CO_2e in the year 2016. SCC values are time-depending (because of the previously mentioned underlying assumptions) but values are not given for each year. For example, the UBA gives a SCC of €205 for the year 2030 based on the FUND model.[16]

For the years for which no values are given, the UBA recommends using linear interpolation.

To calculate the damage costs for the year n, we used the following linear function:

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[14] See Nordhaus, W. (2014). Estimates of the social cost of carbon: concepts and results from the DICE-2013R model and alternative approaches. *Journal of the Association of Environmental and Resource Economists*, *1*(1/2), 273-312.

[15] Stern, N. (2008): The Economics of Climate Change. American Economic Review: Papers & Proceedings 2008, 98:2, 1–37.

[16] Waldhoff et al. (2011): The Marginal Damage Costs of Different Greenhouse Gases: An Application of FUND. Economics E-Journal, October 2014. DOI: 10.2139/ssrn.1974111.

$$monetary\ value_n = 1.7668 * n - 3381.7157$$

which yields, for $n = 2020$:

$$monetary\ value_{2020} = 1.7668 * 2020 - 3381.7157 = 187.234 \frac{€}{t\ CO2\ eq.}$$

After adjusting the value for inflation and converting it to US dollar, a global GHG value of $224.71 per ton CO_2e is obtained for the year 2020.

4.1.2 Air pollution

Overview

Air pollution describes the contamination of the indoor or outdoor environment by any chemical, physical, or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities and forest fires are common sources of air pollution. They cause respiratory and other diseases and are hence an important source of morbidity and mortality.[17] Air pollutants that are being valued are particulate matter with a dimeter 2.5 µm or less ($PM_{2.5}$), particulate matter with a diameter 10 µm or less (PM_{10}), nitrogen oxides (NO_x), sulphur oxides (SO_x), non-methane volatile organic compounds (NMVOC) and ammonia (NH_3).

Harmful effects from air pollutants vary depending on their release environment and tend to be more severe the lower the emission source and the higher the population density near the emission source. Emissions from road traffic, e.g., occur at a very short distance from the ground (release height 0-3 m) and are therefore more strongly absorbed by receptors than emissions from greater release heights.[18] A typical differentiation that also finds application here is between urban, peri-urban, rural, and transport environment.

Impact Pathway

The impact pathways of air pollution are summarized in Figure 4. The figure marks as inputs human activities such as energy production and energy use, resource extraction and others. The output of these activities are air emissions (marked in light blue). The air emissions monetized by WifOR are marked in dark blue in the Output column and include SO_2, $PM_{2.5}$, PM_{10}, NH_3, NO_x, and NMVOCs. Air emissions such as CO (marked in grey) are not monetized. As an outcome of these air emissions, the concentration of the emitted gases increases and air quality declines.

Reduced air quality leads to a multitude of effects. It affects humans directly by causing negative health effects such as respiratory and cardiac diseases. Also, higher particle concentration lowers visibility and thereby increasing shipping and aviation costs. Worse air quality could also lower crop yields in agriculture and impede forests growth. Air pollution may further increase corrosion and thus lead to losses of man-made materials. Further impacts include damages to ecosystems, which may worsen ecosystem services to humans as well as other species. WifOR monetizes impacts on human health, agriculture, man-made materials, and ecosystem services (biodiversity).

[17] World Health Organisation (WHO) (2021): Air Pollution. Accessible under: https://www.who.int/health-topics/air-pollution#tab=tab_1.

[18] Matthey, H., Bünger, B. (2019): Methodenkonvention 3.0 zur Ermittlung von Umweltkosten. Umweltbundesamt, February 2019, ISSN 1862-4804.

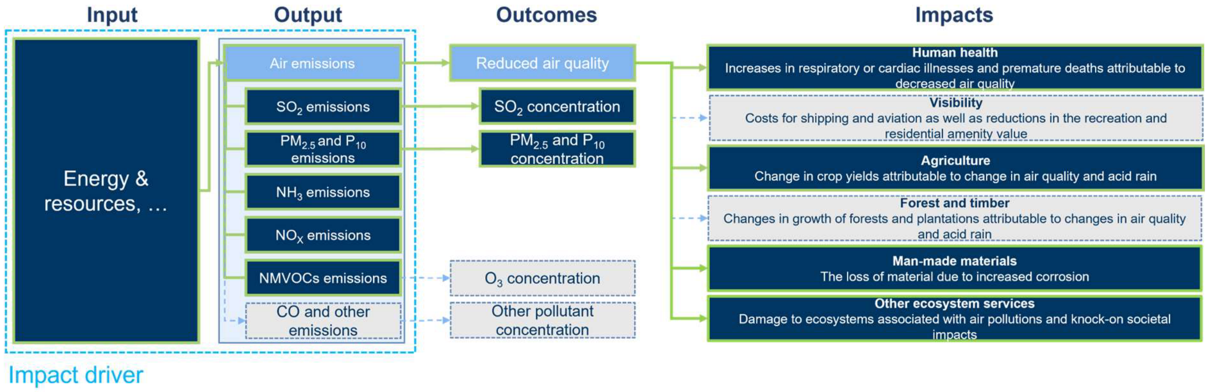

Figure 4: Impact Pathway of air pollution (source: own illustration)

Valuation approach

The valuation of effects arising from air pollution follows the recommendation of the federal German environmental agency (UBA). The UBA provides cost rates which express damages incurring to society due to (Matthey and Bünger, 2019):

1. Health damages (e.g., respiratory diseases)
2. Biodiversity loss (e.g., species extinction)
3. Crop/harvest damages (e.g., losses in agricultural yield)
4. Material/infrastructure damages (e.g., façade staining)

The underlying air quality modeling data is based on the EU project NEEDS.[19] According to NEEDS, health effects of air pollutants are determined based on data compiled from WHO in 2013[20] which subsequently got aligned with current EU standards.[21] Crop losses were determined based on the exposure-response relationship described by Mills et al. (2007).[22] Where this was not possible, as for building/material damage and biodiversity losses, costs were determined from updated NEEDS data.

The UBA recommends the following average damage cost figures for the year 2016 for emission being released from an unspecified source (Matthey and Bünger (2019), Table 2).

€$_{2016}$/t Emission	Health damages	Biodiversity loss	Crop/harvest damages	Material/infra-structure damages	Total
PM 2.5	58,400	0	0	0	58,400
PM10	41,200	0	0	0	41,200

[19] Preiss, P., R. Friedrich, Klotz, V. (2008): Report on the procedure and data to generate averaged/aggregated data (including a MS excel spreadsheet on: External costs per unit emission, Version as of August 21, 2008). Stuttgart, Institute of Energy Economics, and the Rational Use of Energy (IER), University of Stuttgart.

[20] WHO (2013): Health risks of air pollution in Europe – HRAPIE project Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide, World Health Organization, Regional Office for Europe: 54.

[21] Holland, M. (2014): Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air Package - Version 2, Corresponding to IIASA TSAP Report 11, Version 1, EMRC: 67.

[22] Mills, G., Buse, A., Gimeno, B., Bermejo, V., Holland, M., Emberson, L., Pleijel, H. (2007): A synthesis of AOT40-based response functions and critical levels of ozone for agricultural and horticultural crops. Atmospheric Environment 41, pp. 2630-2643.

NOx	14,400	2,600	800	130	17,930
SOx	13,600	1,000	-160	600	15,040
NMVOC	1,100	0	950	0	2,050
NH_3	21,700	10,400	-100	0	32,000

Table 1: Average environmental cost of air pollution from emissions from UBA

Scenario adjustment

The differentiation between rural, peri-urban, urban, and transport environments require a range of adjustments and assumptions. The provided values from an unknown source are hereby assumed to represent a peri-urban environment and are taken as a baseline scenario.

The rate adjustment to an urban environment is made by applying differentiating cost rates for cities provided by the UBA. These represent costs from air pollution released by industrial combustion processes and solely affect human health. Here, we use the average of the different health damage sources in big cities (see Table 3 in Matthey and Bünger (2019)). The deviation to the rates from an unknown source is then applied as a correction factor for "urban".

The UBA further offers cost rates for transport, broken down to various environments (unknow, urban, peri-urban, rural; Table 4 in Matthey and Bünger (2019)). To provide a single number for transport, we first sum health and non-health damages in an unknown transport environment. The deviation to the total peri-urban rates is then applied as a correction factor for "transport".

To adjust the provided cost rates to a rural environment, we assume that the relationship between a peri-urban and a rural environment as provided by the UBA for transport can be applied analogously to the general pollutant cost rates from an unknown source stated in Table 1 here.

This approach then leads to the following correction factors:

Scenario	PM 2.5	PM10	NOx	SOx	NMVOC	NH_3
Urban	+ 55%	+ 55%	-	-	-	-
Peri-urban	**Baseline**					
Rural	- 41%	- 50%	-	-	-	-
Transport	+ 2%	- 83%	+ 3%	+ 4%	+ 7%	+ 4%

Table 2: Adjustment factors for pollutants under study

Together, our Table 1 and Table 2 can be used to derive monetization factors for the total air emissions damages in urban, peri-urban, rural, and transport environments in Germany. Because these rates capture German costs, they cannot be utilized as a global average. In the next section, we describe the additional data sources we employ to produce country specific costs based on the German benchmark.

Local adjustment

Local differences can be reflected by applying adequate metrices per damage category.

A) Biodiversity loss

We assume that the number of endangered species per country correlates with the severity of biodiversity loss and its associated costs. This approach follows Steen (2020) who uses the number of endangered species as a proxy to the threat to biodiversity[23]. Germany is set as the baseline and cost rates are adjusted depending on whether more- or less species are endangered compared to Germany. The number of red-listed species per country is retrieved from IUCN (2021).[24] Three pollutants are linked to biodiversity loss and therefore adjusted: NO_x, SO_x and NH_3. This valuation approach for Air Emissions does not correspond to the biodiversity indicator (4.1.7) and has to be viewed separately.

B) Health damages

As mentioned above, the harmful effects of air pollutants on human health tend to be more severe the higher the population density near the emission source. World Bank data on population density is therefore chosen as a metric to adjust health damages for local differences.[25] Germany is set as the baseline and values are scaled up- and down for more and less densely populated countries. All pollutants under study contribute to health damages and are therefore adjusted.

C) Crop/harvest damages

We assume that societal effects of crop- and harvest damages are more severe the higher the economic dependency of a country on agriculture. The World Bank provides information on which share of a country's GDP is generated from agricultural activities.[26] We normalize these values relatively to the globally reported maximum and set Germany as the baseline. Then we adjust the prices up- and down depending on whether the economic dependency on agriculture is above or below Germany's. The pollutants affecting crops and harvests are NO_x, SO_x, NMVOC and NH_3.

D) Material/infrastructure damages

Following the logic of health damages, damage to material and infrastructure tend to be more severe in densely populated areas. Accordingly, the same correction factor as in health damages finds application. Pollutants affecting material and infrastructure are NO_x and SO_x.

Integration

The cost rates per pollutant are aggregated over the four damage categories to country totals. In a next step, these totals are adjusted to the four release environments whereby peri-urban acts as the baseline and remains constant. For this purpose, the country's totals are treated with the correction factors from Table 2. These correction values are universally applied across countries.

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[23] Steen, B. (2020). Monetary Valuation of Environmental Impacts—Models and Data. Taylor & Francis Group, LLC, p.25.

[24] IUCN (2021): The IUCN Red List of Threatened Species. https://www.iucnredlist.org/resources/summary-statistics.

[25] The World Bank (2020): Population density (people per sq. km of land area). Code: EN.POP.DNST.

[26] The World Bank (2020): Agriculture, forestry, and fishing, value added (% of GDP). Code: NV.AGR.TOTL.ZS.

4.1.3 Waste

Overview

Economic activities result in the generation of solid waste at almost all levels in the supply chain. Poor waste management contributes to climate change and air pollution, and directly affects our ecosystems.[27] Impact pathways vary depending on the type of waste and its end-of-life treatment.

Impact pathway

Solid waste can be characterized as hazardous and non-hazardous waste. Both types may negatively impact the environment and society. The impacts are determined both by the waste type and its treatment. The treatment possibilities are landfill disposal, incineration, and recycling. In monetizing impacts, we focus on landfills and incineration and do not consider recycling.

Landfills are considered the lowest in the waste hierarchy. They release methane, a very powerful greenhouse gas linked to climate change, which is formed by microorganisms present in landfills. Depending on the way landfills are designed, they might also contaminate soil and water through leachate. Landfills further lead to experienced disamenity from undesirable aesthetics.

Incineration describes the combustion of waste during which various types of flue gases and residual fly ashes are created. In addition to regular air pollutants that are released during the process, the incineration of hazardous waste further releases health-damaging heavy metals and dioxins. Just like landfills, incineration plants further lead to experienced disamenity from undesirable aesthetics.

The impacts of recycling waste are not depicted in the flowchart.

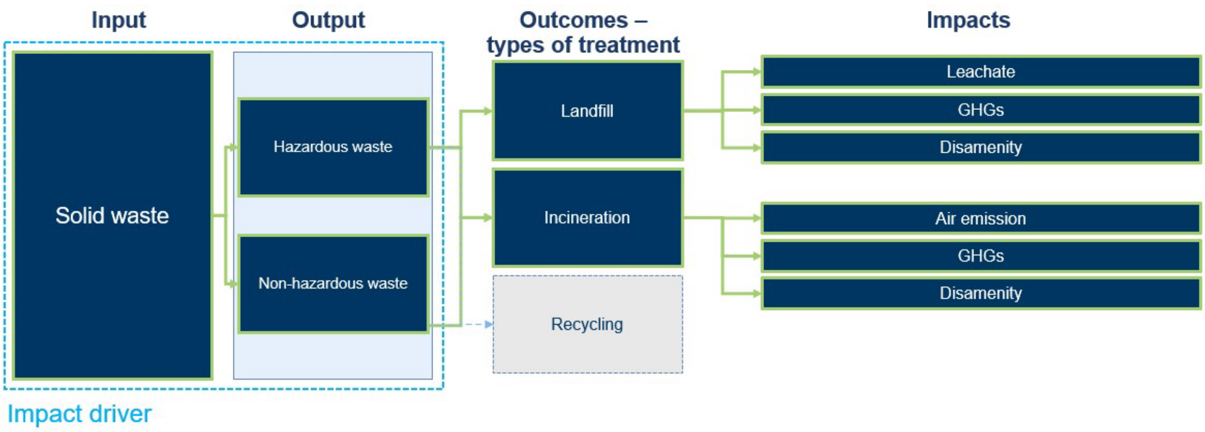

Figure 5: Impact Pathway of waste (source: own illustration)

Valuation approach

The valuation of solid waste follows a mixed approach. Impacts arising from released GHGs and air emission are based on a damage cost approach, disamenity is reflected by hedonic pricing ("willingness-to-pay") and leachate by clean-up-costs. While there is a general endeavor to universally apply a damage cost approach, exceptions have to be made. This is because (1) disamenity is perceived highly individually and can hence not be generalized and

[27] European Economic Area (EEA) (2014): Waste: a problem or a resource? Accessible under: https://www.eea.europa.eu/publications/signals-2014/articles/waste-a-problem-or-a-resource.

(2) the damages of leachate are unknown as its impact pathway is not yet sufficiently understood.[28]

A) Air emission

The incineration of waste releases traditional air pollutants (NO_x, SO_x, $PM_{2.5}$ and PM_{10}) and in the case of hazardous waste also dioxins and heavy metals (arsenic, cadmium, chromium, mercury, nickel, lead). Valuation coefficients that express health damages are provided by EXIOPOL (2009)[29] for heavy pollutants and PwC (2015)[30] for regular air pollutants. These damages were adjusted for inflation to US $2020 using GDP deflator data.

Air pollution leads to respiratory diseases that vary in their severity depending on the level of exposure. Therefore, local coefficients are approximated from the given UK values from EXIOPOL (2009) and US values from PwC (2015). This is done by following the assumption that, the denser an area, the graver will the health effects be. The underlying extrapolation metric is a country's population density in 2020 retrieved from the World Bank.[31]

B) Greenhouse Gas (GHG) emission

GHG emissions arise from hazardous and non-hazardous waste and in both landfills, and incineration plants. While CO_2 is the dominating GHG from incineration, landfills produce a large amount of methane (CH_4).

According to the IPCC (2000)[32], CO_2 is the most significant GHG from waste incineration by at least two orders of magnitude. The amount of CO_2 released per ton of hazardous and non-hazardous waste incinerated is taken from IPCC (2000). These values are based on the carbon content, the fossil carbon fraction, and the efficiency of combustion from waste. A distinction between hazardous and non-hazardous waste is made:

	Non-hazardous waste	**Hazardous waste**
Ton of CO_2 per ton of waste incinerated (2020 USD)	0.557	1.642

Table 3: CO_2 release values from IPCC (2000)

These values are then multiplied with the social cost of carbon retrieved from the German Federal Environmental Agency. After currency conversion and adjustments for inflation, the following valuation coefficients were retrieved:

Variable	**Non-hazardous waste**	**Hazardous waste**
Social Cost of Carbon (CO_2) per ton of waste (2020 USD)	125	369

Table 4: Valuation coefficients for CO_2

GHG gases emitted from landfills highly depend on the type of waste and the conditions of decomposition. Considering the consensus in the literature, methane (CH_4) makes up around

[28] Steen, B. (2020): Monetary Valuation of Environmental Impacts - Models and Data. Published 2020 by Taylor & Francis Group.

[29] EXIOPOL (2009). Final report on waste management externalities in EU25 and report on disamenity impacts in the UK. http://www.feem-project.net/exiopol/M36+/EXIOPOL_PDII_5_b-2.pdf.

[30] PricewaterhouseCoopers (2015): Valuing corporate environmental impacts, PwC methodology document.

[31] The World Bank (2022): Population density (people per sq. km of land area). Data ID: EN.POP.DNST. Accessible under: https://data.worldbank.org/indicator/EN.POP.DNST.

[32] IPCC (2000): Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Chapter 5: Waste.

50-55% of landfill gas and 45-50% of CO_2.[33] Small amounts of other gases include nitrogen dioxide.[34] Zhao (2019) estimated the methane generation per ton of solid waste in the United States at a maximum of 0.135 ton for both hazardous and non-hazardous waste.[35] As methane makes up approximately half of landfill gas and in the absence of better data, the same amount of CO_2 has been assumed to be released.

For the valuation of methane from landfills, the social cost of CH_4 is taken from the Interagency Working Group (IWG) which is adjusted for inflation and converted to USD.[36] The social cost of carbon is the same as stated in Section 4.1.1 (approximately $224 per ton CO_2e in 2020 US dollars).

Variable	Non-hazardous waste	Hazardous waste
Social Cost of carbon (CO_2) and methane (CH_4) per ton of waste (2020 USD)	121	121

Table 5: Valuation coefficients for CH_4

In a last step, the valuation coefficients for CO_2 and CH_4 are summed up per type of waste to create a GHG landfill value.

As GHG emissions are global in their effects, the valuation coefficients are universally applied for all countries.

C) Disamenity

Adverse localised environmental outcomes of waste management sites include noise, odor, pests, and visual intrusion. To estimate the value of disamenity arising from living close to a waste management facility, the societal costs of reduced housing prices are used as a proxy. This approach is called hedonic pricing, which is a type of a revealed preference method. Literature suggests several linear hedonic pricing functions for landfill and incineration sites. Here, values from Cambridge Econometrics EFTEC & WRC are utilized due to their large sample size. The authors estimate the social cost of disamenity to be £2.18 per ton of waste.[37] Adjusted for inflation and converted to US dollar, this leads to a price of $3.46.

Disamenity effects are location specific and according to literature depend on mainly two factors: (1) a country's nominal housing prices (we retrieve data on housing prices from OECD (2022)[38]) and (2) the household density (we retrieve data on household density from UN (2017)[39]). The assumption is that the higher the housing prices, the more severe the effect of

[33] IPCC (2006): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, IPCC Waste Generation, Composition, and Management Data, Chapter 3, v5.

[34] Rieradevall J, Domenech X, & Fullana P. (1997): Application of life cycle assessment to landfilling. Int. J. LCA, 2: 141–4.

[35] Zhao, H. (2019): Methane Emissions from Landfills. Colombia University, Department of Earth and Environmental Engineering. Accessible under: https://epm300.a2cdn1.secureserver.net/wp-content/uploads/2019/06/Methane-Emissions-from-Landfills-Haokai-Zhao.pdf.

[36] IWG (2021): Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

[37] Cambridge Econometrics, EFTEC & WRC (2003): A Study to Estimate the Disamenity Costs of Landfill in Great Britain. www.defra.gov.uk.

[38] OECD (2022): Housing prices. OECD Data. https://data.oecd.org/price/housing-prices.htm.

[39] United Nations, Department of Economic and Social Affairs, Population Division (2017). Household Size and Composition Around the World 2017 – Data Booklet (ST/ESA/SER.A/405).

a property's value reduction and the higher the household density, the more people are affected.

D) Leachate

Leachate is a type of fluid that percolates through the landfill and is generated from liquids present in the waste or from outside water. Leachate occurs due to mismanagement of waste sites. The consequent impacts vary depending on the following factors:

- **Source:** This refers to the quantity and quality of waste. The composition of waste is an important factor in classifying it as hazardous and non-hazardous waste.
- **Pathway:** This is determined by how the leachate escapes the landfill and enters the surroundings. This depends on the leachate collection system as well. The presence of an impermeable liner has major impact on determining if leachate will penetrate its surroundings.
- **Receptor:** This determines how leachate impacts society. For example, the presence of drinking water sources or high population density can lead to higher societal impacts from leachate.

Since there are several risks arising from leachate, a risk-based approach is applied to identify the links between specific end point impacts of leachate and the disposal of waste. We use the social costs of leachate estimated from the Hazard Rating System (HARAS) leachate risk model[40], which is based on source-pathway-receptor relationship. The HARAS model estimates a leachate risk factor, that represents the likelihood and severity of leachate impacts based on source, pathway, and receptor characteristics. The model uses clean-up costs as a proxy to estimate the societal costs. It furthermore provides best-case and worst-case estimates of source, pathway, and receptor indicators. The following table summarizes the concept:

Type of waste	Source rating	Pathway rating	Receptor rating
Non-hazardous	B	W	W
Hazardous	W	W	W

Table 6: HARAS model applied for waste valuation

B hereby stands for *best-case* while W stands for *worst-case*. The source is hereby the input waste, whereby we classify hazardous waste as a worst-case scenario (W) and non-hazardous waste as the best-case scenario (B). As we cannot generalize the pathway and receptor rating (they are site specific), we imply worst-case scenarios to rather over- than underestimate the impact. The pathway here would mean high soil permeability, as it is used as an indicator of how readily leachate will infiltrate the water and soil system. The receptor here is high population density, wherein over 250 people per km^2 are treated as a worst-case scenario.

The HARAS model further differentiates between lined and unlined landfills as the management of sites significantly influences the risk of leachate.

Type of waste	Unlined Landfill	Lined Landfill
Non-hazardous (BWW)	1.24	0.11
Hazardous (WWW)	77.67	6.83

Table 7: Leachate impact values adjusted to 2020 USD

As we cannot distinguish between unlined and lined landfills on a country-level, we again choose to over- rather than underestimate the impact and therefore apply the estimation for an unlined landfill.

Leachate has local effects (e.g., health degradation through contaminated groundwater). Just like for air emissions, the exposure determines the severity of effect. However, the societal

[40] Singh et al. (2012): Evaluating Groundwater Contamination Hazard Rating of MSW Landfills in India and Europe Using a New System: Case Studies. Journal of Hazardous, Toxic and Radioactive Waste.

costs associated with leachate are estimated using the risk score derived from the HARAS model based on the source-pathway-receptor characteristics of the leachate site. We once again assume that the denser an area is populated the more severe the health effects are, using World Bank population density data as a scaling metric.

4.1.4 Water Consumption

Overview

Global water systems feed a growing human population, provide sanitation, and foster blooming ecosystems. Draughts and unproportional withdrawal from that water cycle increases the stress on our water systems. At the current consumption rate, two-thirds of the world's population may face water shortages by 2025. Inadequate freshwater supply exposes them to diseases, such as cholera, typhoid fever, and other water-borne illnesses.[41] Water stress further supports insufficient irrigation of crops that consequently leads to farming losses.

Impact Pathway

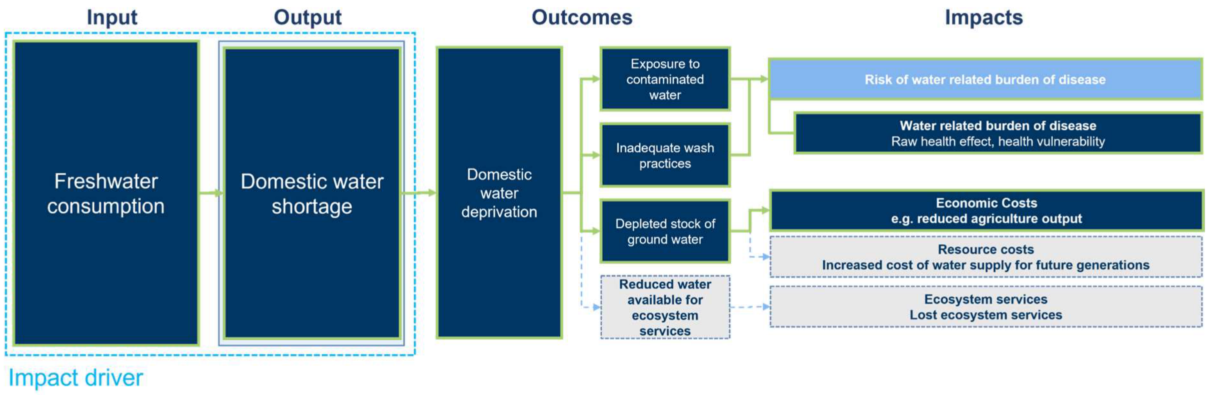

Figure 6: Impact Pathway of water consumption (source: own illustration)

Figure 6 shows the impact pathway of water consumption. As a consequence of commercial water consumption, domestic water shortage might occur. This leads to higher risk of exposure to contaminated water, inadequate wash practices and a depleted stock of ground water. Long-term effect due to the reduced water availability of ecosystem services are not considered in this valuation approach. Water scarcity has an effect on human health, as scarce freshwater might be substituted by polluted water and affect hygienic conditions. The depleted stock of ground water can have direct effects on agricultural output.

Valuation approach

We measure two dimensions of damages. The first one reflects economic damages and the second one comprises damages to human health. These are then summed up to a total damage cost.

- **Economic damages:** The global water shadow price proposed by Lightart and Harmelen (2019) is used as a baseline.[42] The value represents the loss of economic gains in agriculture due to inadequate freshwater supplies that result from 1 m^3 water usage.

[41] WWF (2022): Water scarcity – threats. Accessible under: https://www.worldwildlife.org/threats/water-scarcity.

[42] Ligthart, T.N.; van Harmelen, T. (2019): Estimation of shadow prices of soil organic carbon depletion and freshwater depletion for use in LCA. The International Journal of Life Cycle Assessment (2019) 24:1602–1619. https://doi.org/10.1007/s11367-019-01589-8.

As local water scarcity determines the severeness of these damages, we use country specific water scarcity factors (according to the AWARE model[43]) to reflect these differences. AWARE stands for **A**vailable **WA**ter **RE**maining and expresses the level of water stress per region or country.

- **Damages to human health:** We use Life-cycle Assessment (LCA) characterization factors (CFs) that express the domestic impacts on human health through water consumption.[44] The impact is expressed in Disability Adjusted Life Years (DALYs) per m³ per country. The DALYs are then valued with the statistical value of life (VSL) to estimate the impact on human health through water consumption.

A) Economic Damages

1) Global monetary value

Farming losses due to insufficient water supply are significant economic damages caused by water scarcity. These can be estimated by foregone revenues. Among the different estimates existing in literature, we chose the damage cost for agricultural goods from the study "Estimation of shadow prices of soil organic carbon depletion and freshwater depletion for use in LCA" from Ligthart et. al which values a m³ of water at 5.17 €[45] It is one of the most recent studies for shadow costs of water and can be used in combination with both macroeconomic and process-related inventory data, e.g., for monetizing LCA results.[46] After adjusting the value for inflation and converting it to US dollar, a global water shadow price of 5.89 USD per m³ is obtained for the year 2020.

2) Extrapolation with AWARE factors

AWARE coefficients represent the relative Available WAter REmaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. The coefficients assess the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived. AWARE has published several indicators which are publicly available. Here the "AWARE Improved" table with country-level factors finds application as it is the most recent publication, and it provides a distinction between agricultural and non-agricultural activities.[47] As the global monetary values refer to damages on agricultural goods, we use crop-specific water scarcity characterization factors. The factors range from 0 to 98 with a global average water scarcity factor of 42.

The following formula shows the extrapolation approach for a country i:

[43] WULCA (2021a): What is AWARE? Accessible under: https://wulca-waterlca.org/aware/what-is-aware/.

[44] Debarre, L., Boulay, AM. & Margni, M. Freshwater consumption and domestic water deprivation in LCIA: revisiting the characterization of human health impacts. Int J Life Cycle Assess 27, 740–754 (2022). https://doi.org/10.1007/s11367-022-02054-9.

[45] Ligthart, T.N.; van Harmelen, T. (2019): Estimation of shadow prices of soil organic carbon depletion and freshwater depletion for use in LCA. The International Journal of Life Cycle Assessment (2019) 24:1602–1619. https://doi.org/10.1007/s11367-019-01589-8.

[46] Arendt, R.; Bachmann, T.M.; Motoshita, M.; Bach, V.; Finkbeiner, M. (2020): Comparison of Different Monetization Methods in LCA: A Review. Sustainability (2020) 12:10493, p. 25ff. https://doi.org/10.3390/su122410493.

[47] WULCA (2021b): Download AWARE Factors. Accessible under: https://wulca-waterlca.org/aware/download-aware-factors/.

$$valuation\ coefficient_i = \frac{global\ shadow\ price}{global\ AWARE\ factor} * local\ AWARE\ factor_i$$

B) Damages to Human Health

In contrast to the valuation of economic damages, local valuation coefficients are available for water consumption induced impacts on human health. The values are retrieved from the supplementary information of the article “Freshwater consumption and domestic water deprivation in LCIA: revisiting the characterization of human health impacts” published in *The International Journal of Life Cycle Assessment*. This work consolidates the cause-effect chain linking water use to domestic impacts on human health through characterization factors (CF). The revised CFs range from 0 DALY/m³ (the potential impact on human health due to water use is null with respect to domestic water deprivation) to 3.13E-3 DALY/m³. A DALY is a **D**isability **A**djusted **L**ife **Y**ear. DALYs represent the loss of the equivalent of one year of full health. They are the sum of the years of life lost due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of disease or health conditions. At WifOR, one DALY is universally valued at 200,000 USD (see chapter 3.3). By multiplying the CFs with the valuation of one DALY, a valuation coefficient for water consumption expressed in USD per m³ water consumption is obtained.

$$monetary\ value_i (\frac{USD}{m^3}) = CFi\ (\frac{DALY}{m^3}) * 200{,}000 \left(\frac{USD}{DALY}\right)$$

Assumptions

As can be seen in the impact pathway graph, we do not value all possible damages which occur as a result of water consumption due to data availability. For example, in our coefficients, the impact on ecosystem services or increasing costs for future generations are not valued. This approach is therefore rather conservative.

4.1.5 Water Pollution

Overview

Many economic activities cause water pollution of freshwater through uncontrolled release of chemicals and other substances, if not well managed. These uncontrolled emitted substances can be distinguished in inorganics, organics, and nutrients. Controlled wastewater and its treatment are not considered in our valuation approach.

We value the substances Nitrogen (N), Phosphorus (P), Arsenic (As), Cadmium (Cd), Mercury (Hg), Chromium (Cr), Lead (Pb), Nickel (Ni), Copper (Cu), Zinc (Zn), and Antimony (Sb). Those pollutants have effects on biodiversity, fish production, and human health. The valuation approach outlined in this chapter aims at capturing as many of these effects as possible.

Impact Pathway

Figure 7 represents the simplified impact pathway of water pollution. The green marked path shows the elements considered here. Greyed out elements are not included in the calculation. The reason for this is in particular that these elements already covered in other indicators.

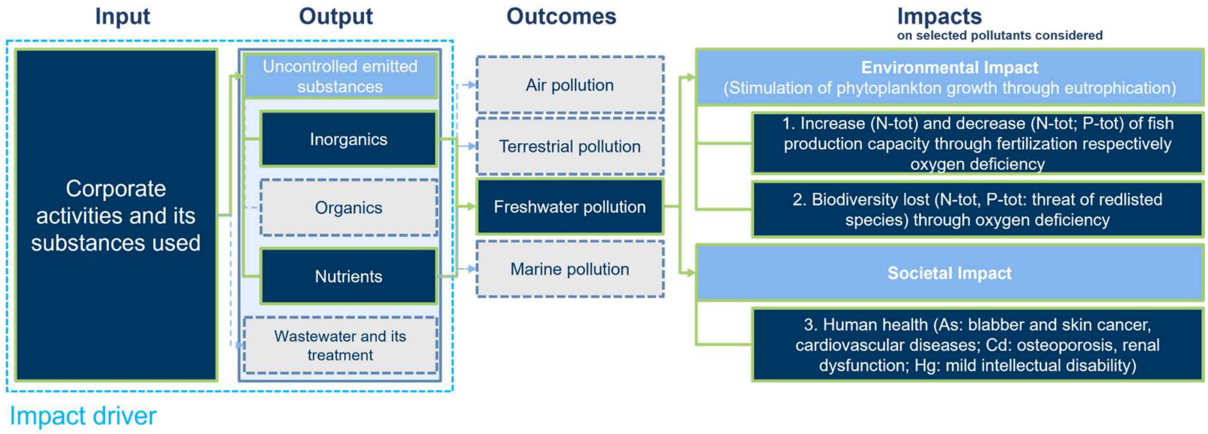

Figure 7: Simplified impact pathway of Water pollution (source: own illustration based on Steen (2020).[48]

Valuation Approach

Steen (2020) provides separate monetary valuations of the substances Nitrogen (N), Phosphorus (P), Arsenic (As), Cadmium (Cd), and Mercury (Hg) which have an effect on water pollution to freshwater.[49] In order to be able to monetize the impact of the additional substances mentioned above, we use the relations between the provided and calculated health related impacts of inorganics by USEtox.[50]

We constructed the indicator via the following steps:

Step 1: Basis of the water pollution indicator are the depictions of global emission to water in Steen 2020[51] in adjusted 2018 US$.

- Nitrogen N-tot to Freshwater 2.40E-03 $/kg N-tot (p.176)
  - N-tot donates total bounded Nitrogen, N2 (free Nitrogen) is not included.
  - Nitrogen N results in loss of biodiversity, and positive and negative effects on fish production capacity.
- Phosphorus P-tot to Freshwater 4.55E-02 $/kg P-tot (p.180)
  - Results in loss of biodiversity and decrease of fish production capacity.
- Arsenic to Freshwater 8.03E+03 $/kg As (p.183)
  - Impact on human health, more specifically blabber and skin cancer, and cardiovascular diseases.
- Cadmium to Freshwater 2.62E+04 $/kg Cd (p.185)
  - Impact on human health, more specifically osteoporosis and renal dysfunction.
- Mercury to Water (and Air) 435 $/kg Hg (p.187)
  - Impact on human health, there are links to mild intellectual disability.

Step 2: Using the Endpoint human health characterization factors [DALY/kg emitted] (CF) in USEtox_2.0 (USEtox_results_inorganics) we adjust the missing pollutants (Chromium, Lead,

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[48] Steen, B. (2020). Monetary Valuation of Environmental Impacts—Models and Data. Taylor & Francis Group, LLC.

[49] Ibid.

[50] USEtox. (2015a). USEtox Manual inorganics. https://usetox.org/support/tutorials-manuals. Downloaded 11.04.2023, USEtox. (2015c). USEtox USER MANUAL. https://usetox.org/support/tutorials-manuals. Downloaded 11.04.2023, USEtox. (2018). USEtox® 2.0 Documentation. 978-87-998335-0-4. Downloaded 11.04.2023.

[51] Steen, B. (2020). Monetary Valuation of Environmental Impacts—Models and Data. Taylor & Francis Group, LLC.

Nickel, Copper, Zinc, and Antimony) based on Mercury. Data describes health-related impacts.[52]

Step 3: For the regional distribution of global data, we use water scarcity data per country from the world bank.[53]

Assumptions

1. Controlled wastewater and its treatment are not considered.
2. For this water pollution indicator, only freshwater pollution is considered.
3. Due to lag of valuation estimates of PAHs (Polycyclic aromatic hydrocarbon) as a water pollutant and different assessments in other environmental compartments we leave these out of estimation.
4. The impact of one kg of a pollutant released into freshwater depends on the volume of the freshwater resources and the availability in a specific region.[54] Therefore, we give a weight on each country according to the water scarcity indicator provided by the world bank.[55] The indicator describes the level of water stress in a country. The level of water stress is the total amount of freshwater withdrawn by the sectors of an economy divided through the total amount of available renewable freshwater resources in a given country.

The above-mentioned methodology has some drawbacks which we mention explicitly:

- The impact calculation is an initial conservative estimate based on data available today. The model is to be refined and supplemented by data generated by scientific research.
- The calculations build on a very divergent current state of research. Currently, no generally recognized calculation approaches are available.
- As described, the calculation approach is not comprehensive but attempts to assess only a portion of the impacts on loss of biodiversity, fish production capacity, and human health.
- For some inorganic pollutants, no reliable estimates were found in the literature. The approach in step 2 is a temporary workaround.
- The regional split based on water scarcity is a rough estimate. The actual regional and local effects of a pollutant released into water depend on a complex distribution of the pollutant in environmental compartments and on the rate of human exposure to the contaminated water. It is therefore not clear to which degree water scarcity aggravates the problem and therefore we use a somewhat arbitrary weight.
- Environmental protection decisions cannot only be made based on monetization. Even if the valuation is sometimes not comprehensive, measures must be implemented to reduce water pollution. Future legal regulations and an increasing demand

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[52] USEtox. (2015b). USEtox (release version 2.0)—Results based on USEtox model 2.0 and inorganic substances database 2.0. https://usetox.org/model/download/usetox2.0. Downloaded 16.11.2022.

[53] The World Bank. (2023). Level of water stress: Freshwater withdrawal as a proportion of available freshwater resources. https://data.worldbank.org/indicator/ER.H2O.FWST.ZS. Downloaded 01.03.2023.

[54] USEtox. (2015a). USEtox Manual inorganics. https://usetox.org/support/tutorials-manuals. Downloaded 11.04.2023, USEtox. (2015c). USEtox USER MANUAL. https://usetox.org/support/tutorials-manuals. Downloaded 11.04.2023, USEtox. (2018). USEtox® 2.0 Documentation. 978-87-998335-0-4. Downloaded 11.04.2023.

[55] The World Bank. (2023). Level of water stress: Freshwater withdrawal as a proportion of available freshwater resources. https://data.worldbank.org/indicator/ER.H2O.FWST.ZS. Downloaded 01.03.2023.

from industry and society, as well as corporate responsibility, justify the resulting risks and opportunities even without a comprehensive monetary assessment of the impacts.
- However, in order to prioritize measures according to their degree of impact, further efforts need to be invested in assessing and monetizing damages.

The result must always be communicated with the underlying assumptions and constraints. The limitations of this estimate must be taken into account when making business decisions based on it.

4.1.6 Land use

Overview

Land use describes the management and modification of a natural environment into a built environment including settlements and semi-natural habitats such as arable fields, pastures, managed woods, and urban environments. Land use occurs constantly and on many scales. It can have specific and cumulative effects on air and water quality, watershed function, generation of waste, extent and quality of wildlife habitat, climate, and human health.[56]

Impact Pathway

Different forms of human land use may affect the environment and society in separate ways. Any type of land use affects the ecological systems (biodiversity). Agricultural land use and mining activities furthermore impact the provision of clean drinking water. Agriculture may also affect crop and wood growth capacity. Paving land for building roads and urban environments imposes all the above costs in addition to other damages (such as, e.g., flooding and landslides), or it may have positive impacts on, e.g., the supply of recreational activities. Moreover, urban land use leads to the existence of urban heat islands in big cities that cause additional deaths, as well as reduction in working capacity and thus productivity.

Here, we focus on monetizing the following economic impacts of different land use forms: effects on working capacity, drinking water treatment costs, crop growth capacity, and biodiversity preservation costs.

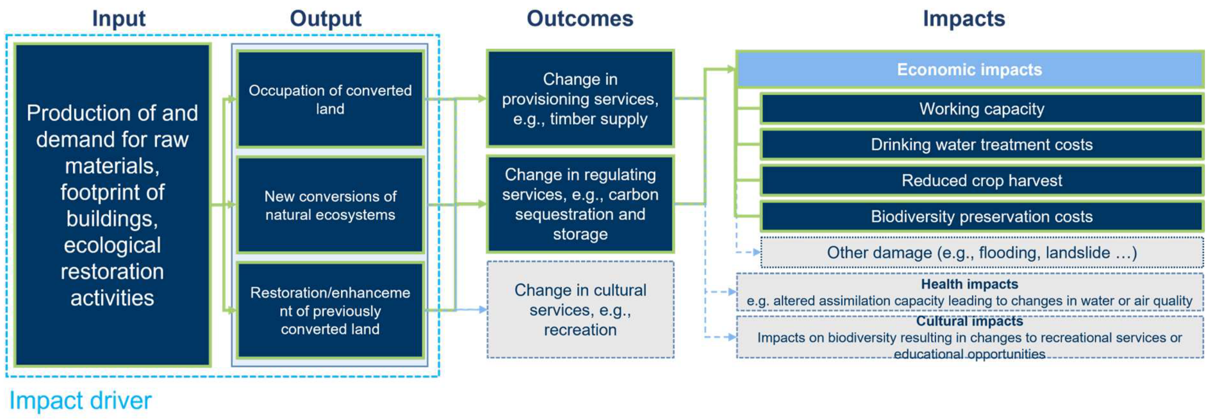

Figure 8: Impact pathway of land use (source: own illustration based on EPS (2015))

[56] EPA (2022): Land Use. Accessible under: https://www.epa.gov/report-environment/land-use.

Valuation approach

One of the first methods developed to value impacts on the environment and human health is the Environmental Priority Strategies (EPS) in 1992.[57,58] The latest version was released 2015 and provides monetary values for various endpoint categories, including land use[59]. The values depict impacts on biodiversity and agricultural damages. EPS land use categories and values were matched to WifOR categories as following as described in the first two columns of Table 8.

WifOR categories	EPS categories	EPS values [$/ha/year]
Agriculture - Animal rearing	Occupation, pasture and meadow	36
Agriculture - Cereal grains nec	Occupation, arable	161
Agriculture - Crops nec	Occupation, arable	161
Agriculture – Oilseeds	Occupation, arable	161
Agriculture – Paddyrice	Occupation, arable	161
Agriculture - Plant-basedfibers	Occupation, arable	161
Agriculture - Sugarcane,sugarbeet	Occupation, arable	161
Agriculture - Vegetables,fruit,nuts	Occupation, arable	161
Agriculture – Wheat	Occupation, arable	161
Forestry	Occup. as Forest land, Occupation, forest, intensive	353
Paved	Occup. as continous urban land, Occup. as rail / road area	5,519

Table 8: EPS land use values assigned to WifOR land use categories.

The EPS values are retrieved from the freely available report "EPS 2015d – including climate impacts from secondary particles" released by the Swedish Life Cycle Center[60,61] - adjusted from 2016 EUR/m² to 2020 USD/ha (third column of Table 8).

According to EPS, different forms of land use affect the environment and humans via their impact on climate change (and thus working capacity), crops and wood growth capacity, drinking water availability, and biodiversity effects.

With respect to the impact of urban land use on working capacity, we build on EPS (2015) using Steen (2016)[62]. Paved surface causes an increase in temperature in densely populated areas. This effect, known as urban heat island effect, increases in combination with global warming. We estimate the impact on reduced working capacity. We need to apply some assumptions to estimate the scope of this impact:

- We assume that 6 billion out of a global population of 9 billion people (in 2050) are in the age of 20-69 years (Steen, 2016).
- We assume an employment rate of 0.65 (Steen, 2016).

57 Arendt, R.; Bachmann, T.M.; Motoshita, M.; Bach, V.; Finkbeiner, M. (2020): Comparison of Different Monetization Methods in LCA: A Review. Sustainability (2020) 12:10493. https://doi.org/10.3390/su122410493.

58 Steen, B. (1999): A systematic approach to environmental priority strategies in product development (EPS). Version 2000– General system characteristics. Gothenburg Centre Environ Assess Prod Material Syst.

59 Swedish Life Cycle Center (2015): A new impact assessment version for the EPS system - EPS 2015d - Including climate impacts from secondary particles. Swedish Life Cycle Center Report 2015:4a, Aug 2015, as Excel file.

60 Ibid.

61 IVL Swedish Environmental Research Institute (2020): Environmental Priority Strategies (EPS). https://www.ivl.se/english/ivl/our-offer/our-focus-areas/consumption-and-production/environmental-priority-strategies-eps.html.

62 Steen, B. (2016): Calculation of Monetary Values of Environmental Impacts from Emissions and Resource Use: The Case of Using the EPS 2015d Impact Assessment Method, Journal of Sustainable Development, 9(6): 16-33.

- Following Steen (2016), we assume the share of manual labor to be 0.3 (manual labor is mainly affected by heat waves).
- Following Steen (2016), each square meter of paved urban land causes a decline of 0,000055 Euro/m^2 in working capacity in the OECD countries in average.
- The EPS (2015) estimate on the rate of decline in working capacity is then multiplied by (6/9)*0.65*0.3, which gives 0.00000715 Euro/m^2 rate of decline.
- We additionally need the global productivity per hour worked. Because such data is not readily available, the following approach was applied. First, OECD's GDP/hour worked for 2019 was extracted from the OECD database. It is equal to USD 52 per hour[63], which gives USD 83,200 per annum assuming again 1,600 hours worked. Then, the ratio of World GDP per capita to OECD GDP per capita was derived from the World Bank and it equals 0.286 in 2019[64]. Thus, the decline in working capacity globally was calculated as 0.00000715*83,200*0.286=0.17 USD/m^2.

A second important driver of land use impact is the effect on drinking water. We obtain the elasticity of the costs of producing water with respect to the different types of land use surrounding the water source from Price and Heberling (2020)[65]. They measure the effects of urban and agricultural land use on the variable water production costs relative to forest land use and take two different water sources into account: surface water and groundwater. They find that with respect to surface water, only urban land use has a statistically significant effect on the costs, while with respect to groundwater, only agriculture (pasture) has a significant effect.

The elasticities were recalculated in marginal variable cost per m^2 of land use. Because each of these effects applies either to surface water or to groundwater, one needs an estimate for the share of each source in the global water supply. The UN states in its Groundwater report that each source provides roughly a half of the global water supply[66]. Hence, to estimate the global effect of, e.g., urban land use on water supply, its effect on surface water was multiplied by 0.5.

While an issue with these estimates is that they are based on the US, no data was found that applies globally. The main assumption here is that water purification technology is globally homogenous and has a global price that does not differ too much across countries.

Lastly, we estimate the impact from land use on biodiversity costs. We use a source from 2020 that estimates an upper bound for the financial costs equal to US$967 billion per year measured in 2019 USD[67]. We use an estimate of the share of threatened species from the IUCN

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[63] https://data.oecd.org/lprdty/gdp-per-hour-worked.htm.

[64] World GDP per capita was US$11320,9 in 2019 (Source: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD). OECD GDP per capita in 2019 was US$39531,7 (Source: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=OE).

[65] Price, J. and M. Heberling (2020): The Effects of Agricultural and Urban Land Use on Drinking Water Treatment Costs: An Analysis of United States Community Water Systems, Water Econ Policy, 6(4): 1-24.

[66] The United Nations World Water Development Report 2022: Groundwater, Making the invisible visible.

[67] Deutz, A., Heal, G. M., Niu, R., Swanson, E., Townshend, T., Zhu, L., Delmar, A., Meghji, A., Sethi, S. A., and Tobin-de la Puente, J. (2020): Financing Nature: Closing the global biodiversity financing gap. The Paulson Institute, The Nature Conservancy, and the Cornell Atkinson Center for Sustainability.

website[68] (version at time of update 2022-2). Furthermore, we use World Bank data on road length to calculate the biodiversity costs per m^2 of roads and railroads.[69]

Additionally, when mapping the EPS categories to the categories in the first column of Table 8, two averages were taken. First, Forestry was calculated as a simple average of Occupation as Forest Land and Occupation, forest, intensive (EPS Categories). Second, paved land use was calculated as a weighted average of Occupation as continuous urban land and Occupation as rail/road area according to their global areas.

The EPS valuation method provides global values which neglect regional differences from the use of one hectare of land. We correct the global values for country differences by applying so-called characterization factors (CF). CFs are a quantitative representation of the (relative) importance of a specific intervention and are commonly used in LCAs. Here LANCA characterization factors recommended by the EU are applied to regionalize valuation impacts.

LANCA factors assess the impacts of land-use processes on ecosystem services.[70, 71] Processes that find consideration are erosion resistance, mechanical filtration, physicochemical filtration, groundwater replenishment, and biotic production. Biotic production potential represents the ability of an area to produce biomass and is hence a suitable indicator to assess the current state and well-being of land. The potential can be positive (biotic production gains) and negative (biotic production losses). An example of positive potential is the conversion of a desert-like area to commercial forest land. The factors are classified into types of land use (agriculture, forest, paved). The underlying assumption of applying LANCA CFs is that "positive" effects (e.g., afforestation) and "negative" effects (e.g., sealing forest land) intensify highly potential land and weaken on less potential land.

Local valuation coefficients can then be derived as following:

$$local\ monetary\ value_i = \frac{global\ monetary\ value}{global\ LANCA\ factor} * local\ LANCA\ factor_i$$

Where the index i stands for country i and goes from 1 to 188 covering the 188 countries in WifOR's database.

4.1.7 Biodiversity

Overview

Biodiversity describes the variety of living species on Earth, including plants, animals, bacteria, and fungi. While many species have yet to be discovered, other species are being threatened with extinction due to human activities.[72] The WWF's 2022 Living Planet Report estimates an average 69% decline in global populations of mammals, fish, birds, reptiles, and amphibians

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[68] Source: https://www.iucnredlist.org/search.

[69] Meijer, J., Huijbregts, M., Schotten, K. and A. Schipper (2018): Global patterns of current and future road infrastructure, Environmental Research Letters 13, 064006.

[70] Bos, U.; Horn, R.; Beck, T.; Lindner, J.P.; Fischer, M. (2016): LANCA® Characterization Factors for Life Cycle Impact Assessment Version 2.0. FRAUENHOFER VERLAG. http://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-3793106.pdf.

[71] Frauenhofer IBP (2021): LANCA® characterization factors. https://www.ibp.fraunhofer.de/en/expertise/life-cycle-engineering/applied-methods/lanca.html.

[72] National Geographic (2022): Encyclopedic entry "Biodiversity". Accessible under: https://education.nationalgeographic.org/resource/biodiversity.

since 1970.[73] The complexity and interconnectedness of ecosystems however make an assessment and valuation difficult. As Steen (2020) described it: "*Biodiversity has several values. It is a genetic bank; it strengthens ecosystem resilience, and it supports ecosystem services. Present knowledge is not sufficient to allow quantitative modelling of the links between biodiversity characteristics and satisfiers to human needs. The role of biodiversity for ecosystem services is, at most, known for single issues, such as the threat to pollinators. Therefore, biodiversity is valued by the costs of conservation measures to preserve it on the level which today is implied or deemed necessary*."[74]

Valuation approach

In the book "Monetary Valuation of Environmental Impact factors – Models and Data", Steen developed a model to estimate impacts on biodiversity from single human activities. The valuation is based on the cost of preventing biodiversity from declining – an abatement cost approach. We follow Steen's suggestions and consider various physical interventions that are linked to a decline in biodiversity. These are namely: Air pollution (CO_2, CO, CH_4, N_2O, NH_3, NO_x, SO_x, PM10, NMVOC), Water pollution (nitrogen, phosphorus), Land use (agriculture, animal rearing, forestry, paved).

Biodiversity conservation costs

An estimation of the global value of biodiversity recently published in Financing Nature, was expressed as the total financial costs of meeting global biodiversity conservation targets. The authors estimate these costs between 722 - 967 billion $/year[75]. We use the upper value to rather over- than underestimate impacts on biodiversity.

Environmental impact factors

Steen (2020) provides so-called environmental impact factors per impact category. These are based on the assumption that changes in biodiversity from a single human activity can be seen as an activity's share of threats to red-listed species. Following that logic, environmental impact factors for the valuation of biodiversity are the share of threat to red-listed species. The factor units are dimensionless. More details about threat causes for red-listed species can be found in IUPCN's database.[76]

By multiplying the environmental impact factors with the global biodiversity conservation costs, impact values expressed in dollars per activity unit are retrieved, where the index i represents the biodiversity-affecting activities:

$$\text{impact value}_\text{i} = \text{environmental impact factor}_\text{i} \, * \, 9.67\text{E} + 11$$

The following table displays the applied environmental impact factors and their corresponding impact value.

Activity impacting biodiversity	Unit	Environmental impact factor	Impact value [$/unit]
NMVOCs	kg NMVOC	8,06E-16	7.79E-04

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[73] WWF (2022:) Living Planet Report 2022 – Building a nature-positive society. Almond, R.E.A., Grooten, M., Juffe Bignoli, D. & Petersen, T. (Eds). WWF, Gland, Switzerland.

[74] Steen, B. (2020): Monetary Valuation of Environmental Impacts - Models and Data. Published 2020 by Taylor & Francis Group.

[75] Deutz, A., Heal, G. M., Niu, R., Swanson, E., Townshend, T., Zhu, L., Delmar, A., Meghji, A., Sethi, S. A., and Tobin-de la Puente, J. (2020): Financing Nature: Closing the global biodiversity financing gap. The Paulson Institute, The Nature Conservancy, and the Cornell Atkinson Center for Sustainability.

[76] IUCN (2022): The IUCN Red List of Threatened Species. Version 2021-3. ISSN 2307-8235. Accessible under: https://www.iucnredlist.org.

NOx	kg Nox	-2,23E-15	-2.16E-03
PM10	kg PM10	5,58E-14	5.40E-02
SOx	kg Sox	-3,93E-15	-3.80E-03
CH4	kg CH4	4,732E-15	4.58E-03
CO	kg CO	5,92E-16	5.72E-04
CO2	kg CO2	1,69E-16	1.63E-04
N2O	kg N2CO	4,48E-14	4.33E-02
NH3	kg NH3	1,30E-14	1.26E-02
Land use animal rearing	m^2year	3,33E-15	3.22E-03
Land use agriculture	m^2year	1,07E-14	1.03E-02
Land use forest	m^2year	2,00E-14	1.93E-02
Land use paved	m^2year	1,30E-13	1.26E-01
Nitrogen water pollution	kg N-tot	2,06E-14	1.99E-02
Phosphorus water pollution	kg P-tot	1,83E-13	1.77E-01

Table 9: Impact values of selected activities impacting biodiversity following Steen (2020).

Local adjustments

The sourced rates capture a global average. However, we assume that the number of endangered species per country correlates with the severity of biodiversity loss and its associated costs. If a country demonstrates a higher share of threatened species compared to the global average, the severity of biodiversity loss is valued higher and vice versa. The relative deviation of threatened species from the global mean value is utilized as a proportional scaling factor. Specifically, the scaling factor for each country is defined as the number of threatened special in this country divided by the total number of threatened species globally.

$$scaling\ factor\ of\ country_i = \frac{number\ of\ threatened\ species\ in\ country_i}{total\ number\ of\ threatened\ species\ globally}$$

The number of red-listed species per country is retrieved from IUCN statistics. Then, we calculate country-specific environmental impact values by multiplying the global environmental impact value of each activity by the scaling factor of the respective country and dividing by the mean of all scaling factors. Hence, if a country has the same scaling factor as the average country globally, then its local impact value is equal to the global impact value derived in the previous section. A country with a scaling factor above (below) the average has a monetary environmental impact value that is also above (below) the global average.

Thus, using the scaling factor, we can calculate the local impact value as

$$Impact\ value\ in\ country_i\ and\ activity_j = \frac{scaling\ factor\ of\ country_i}{mean\ of\ scaling\ factors} * global\ impact\ value_j$$

Future research

Steen (2020) further provides environmental impact factors for BOD: Arsenic, Cadmium, and Mercury to freshwater. As of now, these are not included as physical data on their pollution concentration is not statistically collected. They will be added in the future once resilient data is available.

In general, research on how to measure and value biodiversity is a widely discussed topic in the scientific community with new assessment methods and reporting guidelines being published regularly. The described method will remain in place until a consensus can be reached and is hence subject to change in the near future.

4.1.8 Marine plastic leakage

Overview

The disposal of plastic causes several negative impacts to the environment, society, and economy. The fate of plastic waste hereby depends on several parameters: the type of waste, its end-of-life treatment, and the size of plastic particles. Due to restricted data availability, we focus on the **effects of macroplastic on ecosystem services of oceans caused by maritime plastic leakage**.

Macroplastics are fragmentations of plastic larger than 5 mm. They damage ecosystems especially because of pollution and entanglement of animals. Larger particles become smaller and smaller over time due to degradation processes (UV radiation, temperature differences, or physical abrasion), leading to the effects of micro (<5 mm) and nano plastic (<1 µm). These smaller particles are ingested or inhaled. Thus, they affect the health of humans and animals.[77] As of now, data to depict the effects of micro and nano plastic is missing.[78]

Ecosystem services contribute significantly to human wellbeing and welfare of the society which are disturbed by maritime plastic leakage. The disturbances include (1) effects on fisheries, aquaculture, and agriculture, (2) damages to natural heritage (extinction of species), (3) impacts on experiential recreation.

Plastic leakage usually origins from mismanaged waste (82%[79]). In general, end-of-life fates are grouped to recycling, incineration and discarding. Discarding is further subdivided into sanitary landfill, mismanaged waste, and littering.

Health as a cost dimension by plastic lifecycle is unquantifiable at the moment (WWF International & Dalberg, 2021, p. 15). Health cost can arise from production processes, waste management processes, period of use, and uncontrolled plastic waste. Studies show a link between plastic and human health, but the exact impact cannot yet be quantified (Wright & Kelly, 2017). Among other things, this is because the impact of plastic on human health depends on the amount, but at the moment there are no robust data. Further research is needed to determine the effects of plastic waste on health and thus derive a monetarization (Woods et al., 2021; Wright & Kelly, 2017).

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[77] Woods, J. S., Verones, F., Jolliet, O., Vázquez-Rowe, I., & Boulay, A.-M. (2021): A framework for the assessment of marine litter impacts in life cycle impact assessment. Ecological Indicators, 129, 107918. https://doi.org/10.1016/j.ecolind.2021.107918.

[78] Wright, S. L., & Kelly, F. J. (2017): Plastic and Human Health: A Micro Issue? *Environmental Science & Technology*, *51*(12), 6634–6647. https://doi.org/10.1021/acs.est.7b00423.

[79] OECD (2022a): *Global Plastics Outlook*. https://doi.org/10.1787/de747aef-en.

Impact Pathway

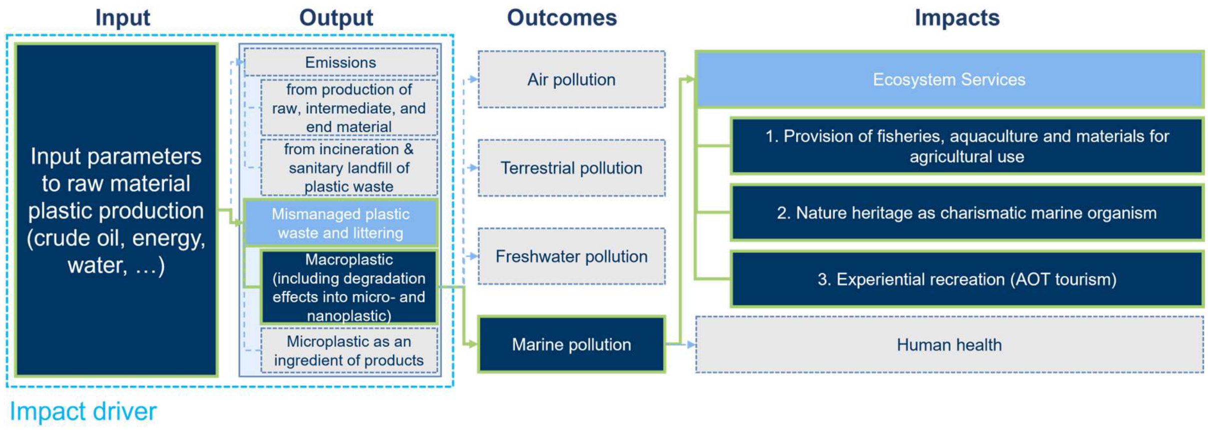

Figure 9: Simplified impact pathway of marine plastic leakage (source: own illustration)

Valuation approach

To calculate the impact of leaked plastic to the aquatic environment, the transportation, fragmentation, and degradation of plastic have to be considered.[80,81]

Leaked plastic in the ocean per year is summed up and divided by the sum of global plastic production in order to obtain an ocean leakage rate. The amount of leaked plastic into the aquatic environment is retrieved from OECD.[82] Further in alignment with the OECD,[83] we use the plastic production mass from PlasticsEurope.[84] The global plastic ocean leakage rate is applied for all countries to estimate the amount of plastic ending in the ocean.

To value the arising damage from that leakage, the WWF's value estimate for ecosystem services is utilized. The WWF assumes a global value of 61.3 trillion $/year for marine ecosystem services.[85] Beaumont et al. (2019) assume a reduction in ecosystem services because of marine plastic between 1-5%. This damage estimate includes the economic loss due to the reduced provision of fishery, aquaculture and materials for agricultural use, the welfare loss due to the destruction of natural heritage (for example the reduction of charismatic species like sea turtles), and the economic loss due to reduced recreational service (e.g. due to polluted beaches). Using the conservative estimate of 1%, this results in a minimum cost of 4,085 $ per ton of leaked plastic into the maritime environment in one year according to WWF International,

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[80] Beaumont, N. J., Aanesen, M., Austen, M. C., Börger, T., Clark, J. R., Cole, M., Hooper, T., Lindeque, P. K., Pascoe, C., & Wyles, K. J. (2019). Global ecological, social and economic impacts of marine plastic. *Marine Pollution Bulletin*, *142*, 189–195. https://doi.org/10.1016/j.marpolbul.2019.03.022.

[81] WWF International, & Dalberg. (2021). *Plastics: The costs to society, the environment and the economy*. https://wwfint.awsassets.panda.org/downloads/wwf_pctsee_report_english.pdf.

[82] OECD (2022b): Plastic leakage in 2019 Accessible under: https://doi.org/10.1787/108fd7fd-en.

[83] OECD. (2018): Improving Markets for Recycled Plastics. Accessible under: https://doi.org/10.1787/9789264301016-en.

[84] PlasticsEurope. (2020): Plastics – the Facts 2020. Accessible under: https://plasticseurope.org/knowledge-hub/plastics-the-facts-2020/.

[85] Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014): Changes in the global value of ecosystem services. Global Environmental Change, 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002.

& Dalberg. (2021).[86] The lifetime costs of plastic leaked into the ocean is then derived by applying a social discount rate of 1.5%.

The amount of leaked plastic into the ocean is ultimately multiplied with the minimum costs of loss of marine ecosystem services to obtain damage costs.

Assumptions

Waste management differs locally and can be handled responsibly. However, due to data restrictions, a universal leakage rate is assumed. Another assumption is that the stock of plastic (1) does not depreciate and (2) causes harm forever. This is suggested by literature.

4.2 Social indicators

4.2.1 Occupational injuries and illnesses

Overview

Occupational injuries and illnesses are health impairments resulting from incidents that happen during employment. Cases are distinguished into fatal and non-fatal injuries and illnesses.

Negative impacts caused by occupational injuries and illnesses are experienced by three groups of stakeholders: employers, employees, ~~and~~ the local community and wider society. There is a wide range of types of cost caused by occupational injuries and illnesses, for example production losses, long-run losses of human capital, health-care related cost, administrative cost, or negative impacts on human well-being, and loss of life quality. The distribution of the overall cost across these stakeholders differs by country, among other factors depending on the social security system.[87,88]

[86] WWF International, & Dalberg. (2021). Plastics: The costs to society, the environment and the economy. https://wwfint.awsassets.panda.org/downloads/wwf_pctsee_report_english.pdf.

[87] Safe Work Australia (2015): The Cost of Work-related Injury and Illness for Australian Employers, Workers and the Community: 2012–13. https://www.safeworkaustralia.gov.au/resources-and-publications/statistical-reports/cost-work-related-injury-and-illness-australian-employers-workers-and-community-2012-13.

[88] European Agency for Safety and Health at Work (2019): The value of occupational safety and health and the societal costs of work-related injuries and diseases. https://osha.europa.eu/en/publications/value-occupational-safety-and-health-and-societal-costs-work-related-injuries-and/view).

Impact Pathway

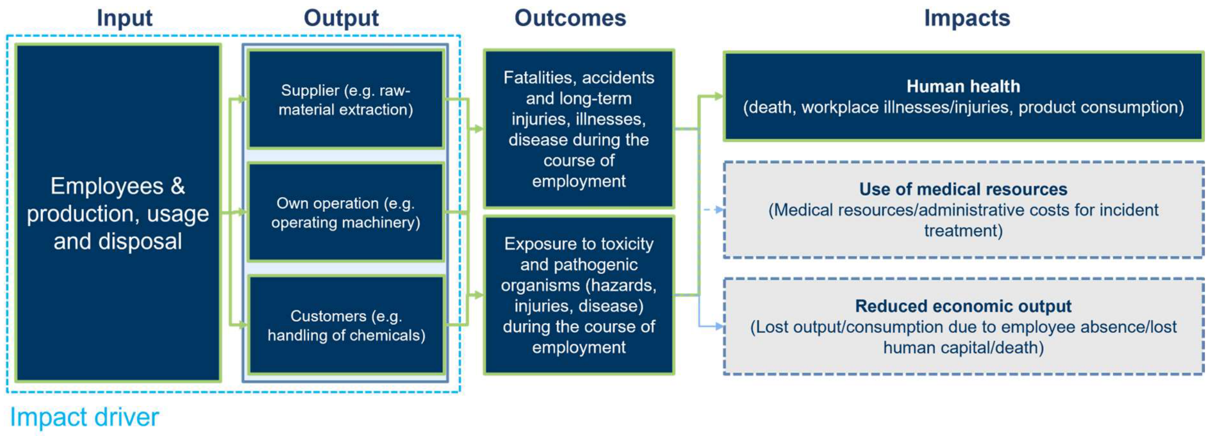

Figure 10: Simplified impact pathway of Occupational injuries and illnesses

Our analysis is limited to impacts on human health and therefore a rather conservative approach.

Valuation Approach

This valuation focuses on the impacts on the wellbeing of the affected employees due to health impairment. As the impacts of injuries and illnesses depend on the type, severity and duration, a normalization of the variety of health impairments is necessary. As described in chapter 3, in health policy and economics, different health states are commonly translated into Disability-Adjusted-Life-Years (DALYs) to measure the burden of disease. DALYs express the sum of years of life lost due to premature mortality (YLL) and years lived with disability (YLD).

For fatal incidents, the "years of life lost" due to premature mortality are estimated, using the median age of the workforce[89] and their life expectancy.[90] For nonfatal incidents, the "years of life lived with a disability" (YLD) caused by the condition are estimated, using Eurostat data on the type of injuries/illnesses and duration of absence from work. The DALYs for each category are then valued with the common impact of 200,000 USD per case (compare chapter 3.3):

$$impact\ per\ case_i = DALYs\ per\ case_i * 200.000 \frac{USD}{DALY}$$

with $i \in$ [fatality, non-fatal injuries, non-fatal illnesses]

Fatal Injuries and Illnesses

The years of life lost (YLL) due to the premature death caused by the occupational incident, are defined as the difference between the age of death and life expectancy. This absolute number of years is then age weighted. A year life free of disability does not hold the same number of DALYs for all ages. People place a higher value on avoiding disability between the early teens and the mid-50s. A social discount rate (SDR) of 1.5% is applied to future years.

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[89] ILO (2019): Median age of the labour force by sex -- ILO modelled estimates, Indicator EAP_2MDN_SEX_NB. Estimates for 2019.

[90] WDI Indicators database (2021): SP.DYN.LE00.IN: Life expectancy at birth, total (years).

Based on the age-weighting and discount formula commonly used in the literature, e.g., by the World Health Organization[91,92], the following equations yield the DALYs per country:

$$DALY_{fatality} = YLL = \sum_{x=\,median\ age}^{life\ expectancy} \frac{C * x * e^{-\beta x}}{(1+SDR)^{(i-median\ age)}} = \sum_{x=\,median\ age}^{life\ expectancy} \frac{0.1658 * x * e^{-0.04\mathrm{x}}}{(1+0.015)^{(i-median\ age)}}$$

Due to the age-weighting and discounting influenced by the demographic characteristics of each country, the coefficients are country-specific. The parameters C=0.1658 and β=0.04 are age-weighting parameters which give higher weight to persons which are closer to the median age.

Non-Fatal Injuries and Illnesses

Estimating the years of life lived with a disability (YLD) caused by the condition requires an estimate on the severity of life quality reduction in comparison to a perfect health state, i.e., the disability weight, and an estimate on the duration of this state. These are derived using Eurostat data on diagnoses[93,94] through occupational illnesses and injuries respectively for the European Union aggregate. The diagnoses are matched with an average severity disability weight from the Global Burden of Disease 2013 study.[95] For the length of impairment, the length of absence average weighted by number of cases was calculated.[96,97]

To derive the DALYs, i.e., years of life lived with a disability, an age-weighting is applied as described above. Country-specific values thus emerge based on the median age of the work-force.

$$DALYs = YLD = disability\ weight * \frac{(days\ of\ absence)}{365\ days} * C * x * e^{-\beta}$$

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[91] Murray, C.J.L. (1994): Quantifying the burden of disease: the technical basis for disability-adjusted life years, in: WHO Bulletin OMS, Vol. 72, pp. 429-445.

[92] Prüss-Üstün, A.; Mathers, C.; Corvolán, C.; Woodward, A. (2003): Assessing the environmental burden of disease at national and local levels, Environmental Burden of Disease Series No. 1, WHO, Geneva.

[93] Eurostat (2022a): Persons reporting a work-related health problem by sex, age and type of problem [hsw_pb5]. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_pb5&lang=en. Extracted on 16.06.2022.

[94] Eurostat (2022b): Accidents at work by type of injury and severity (NACE Rev. 2 activity A, C-N) [hsw_mi07]. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_mi07&lang=en. Extracted on 16.06.2022.

[95] Salomon, J.A.; Haagsma, J.A.; Davis, A.; Maertens de Noordhout, C.; Polinder, S.; Havelaar, A.H., Cassini, A., Devleeschauwer, B.; Kretzschmar, M.; Speybroeck, N.; Murray, C.J.L.; Vos, T. (2015): Disability weights for the Global Burden of Disease 2013 study, in: Lancet Global Health, vol. 3, e712–23.

[96] Eurostat (2022c): Persons reporting a work-related health problem resulting in time off work by period off [hsw_pb3]. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_pb3&lang=en. Extracted on 16.06.2022.

[97] Eurostat (2022d): Accidents at work by days lost, sex and age (NACE Rev. 2 activity A, C-N) [hsw_mi02]. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_mi02&lang=en Extracted on 16.06.2022.

There is no discounting because only impacts on life quality in the present year are valued.

4.2.2 Child labor

Overview

Child labor is "defined as work that deprives children of their childhood, their potential and their dignity, and that is harmful to physical and mental development".[98] Here, a case of child labor is defined as a child engaged in economic activities for more than one hour per week if aged 5-11, for more than 14 hours per week if aged 12-14, and for more than 43 hours per week if aged 15-17. This includes but is not limited to hazardous work but excludes household chores.[99]

Although the children working may experience some benefits (e.g., better nutrition, greater control over resources being spent in their favor)[100], there is a variety of negative impacts on children and society that overall exceed potential benefits[101]. For example, children have a higher risk of injury or fatality when working in low-skill-jobs or may incur mental health damage through exposure to violence. These harms can have not only short- but potentially also long-term implications for their health. The impacts are, however, difficult to quantify due to lack of data.[102,103]

Child labor has longer-term negative impacts for the children and society when children are deprived of school education and thereby lose future productivity and income earning opportunities. Using returns to education, we approximate the income and productivity lost in terms GDP p.c. in PPP for one year of work. The net present value of the future losses during the adult work life is estimated. This approach to quantify the cost of child labor is common in the literature.[104] The result is a country-specific economic damage cost estimate for a case of child labor.

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[98] ILO (2019): What is child labour. International Labour organization. Retrieved from: https://www.ilo.org/ipec/facts/lang–en/index.htm.

[99] ILO & UNICEF (2021): Child Labour: Global estimates 2020, trends and the road forward. https://www.ilo.org/ipec/Informationresources/WCMS_797515/lang--en/index.htm.

[100] Edmonds, E.V. (2008): Economic Growth and Child Labor in Low Income Economies. GLM|LIC Working Paper No. 11, April 2016.

[101] Gordon, J. (2008): The Economic Implications of Child Labor. A Comprehensive Approach to Labor Policy. https://sites.duke.edu/djepapers/files/2016/11/Gordon.pdf.

[102] Vionnet, S.; Friot, D.; Haut, S.; Adhikari, R. (2021): Screening for human rights impact in corporate supply chains. A methodological proposal for quantitative assessment and valuation — Novartis case study. Working Paper. https://www.valuingnature.ch/post/measuring-human-rights-impact-in-corporates-supply-chains.

[103] Pereznieto, P.; Montes, A.; Langston, L.; Routier, S. (2014): The costs and economic impact of violence against children. https://childhub.org/en/child-protection-online-library/costs-and-economic-impact-violence-against-children.

[104] World Vision (2016): Eliminating child labour, achieving inclusive economic growth. Policy Paper, October 2016.

Impact Pathway

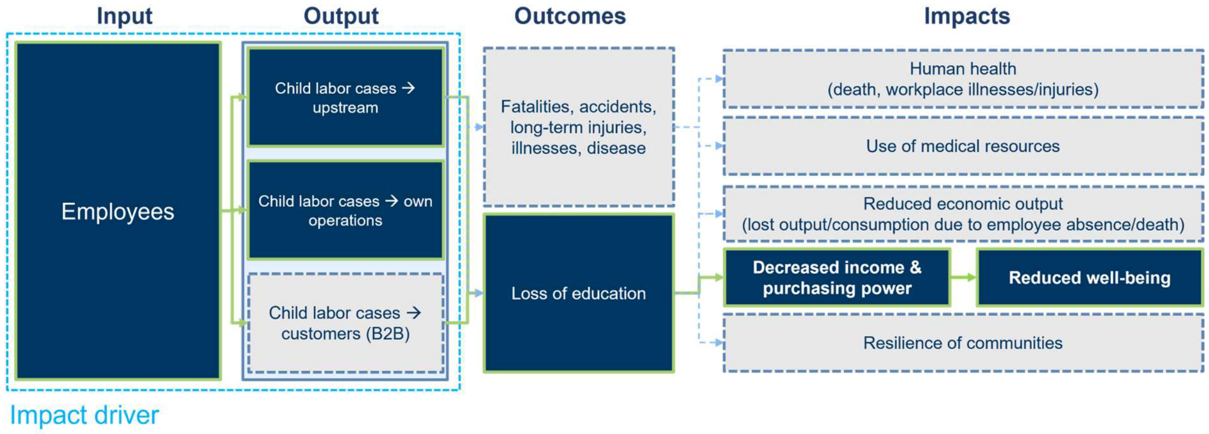

Figure 11: Simplified impact pathway of Child labor

Valuation approach

A) Returns to schooling and the estimate for income and productivity

The most recent source on income returns to a year of schooling is provided by Psacharopoulos & Patrinos.[105] We use the overall returns to schooling, estimated by the Mincerian rate of return. Returns toon education over all grades are chosen as we are interested in returns to education across all age groups. There are estimates for 103 countries. For the remaining countries, we take the average of the world region and income region averages following the World Bank classifications.

The absolute productivity loss per year is the return to schooling in percent times the average income in the country. We use the 2020 per capita values for gross domestic product (GDP) expressed in current international dollars converted by purchasing power parity (PPP) conversion factor[106] to reflect both impacts on individual income and the productivity potential losses incurred by the society.

B) Adult working life

To estimate income and productivity losses over the lifetime, the adult working life in the country is considered, taking the difference between age 18 and official retirement age. Where the official retirement age is less than 5 years higher than the life expectancy of a currently 11-year-old, we deduct 5 years from the average life expectancy of a child to approximate the end of working life. The net present value is calculated with a 1.5% discount rate.

Life expectancy at birth, i.e., the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life, is taken from the WDI Indicators Database.[107]

The official retirement age is estimated using four sources depending on availability, in the following order of preference:

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[105] Psacharopoulos, G. & Patrinos, H.A. (2018): Returns to Investment in Education. A Decennial Review of the Global Literature. World Bank Policy Research Working Paper 8402. https://openknowledge.worldbank.org/handle/10986/29672.

[106] WDI Indicators database (2021a): NY.GDP.PCAP.PP.CD: GDP per capita, PPP (current international $).

[107] WDI Indicators database (2021b): SP.DYN.LE00.IN: Life expectancy at birth, total (years).

- OECD[108], providing the current retirement ages for a person who entered the labor force at age 22 (general or men if differentiated by gender),
- International Social Security Association[109], collecting the statutory pensionable age,
- The Social Pensions Database by Pension Watch[110], providing the age of eligibility for social pension schemes,
- and individual research for the remaining countries.

Assumptions

Not all children considered as child labor cases do not go to school. In fact, only "[m]ore than a quarter of children aged 5 to 11 and over a third of children aged 12 to 14 who are in child labor are out of school. This severely constrains their prospects for decent work in youth and adulthood as well as their life potential overall."[111] As detailed data on the number of hours worked and participation in school is not available, we assume that each case of child labor equals the loss of one year of schooling. The estimates therefore tend to overestimate the impacts of child labor caused by lack of education. On the other hand, we exclude impacts on human health and future economic output.

4.2.3 Forced labor

Overview

Forced labor exploitation is defined as work forcefully imposed by private agents, including bonded labor, forced domestic work, and work imposed in the context of slavery or vestiges of slavery. Other forms of forced labor – forced sexual exploitation and state-imposed forced labor– are not considered here. Forced labor is a form of modern slavery.[112]

Forced labor has different effects on the life quality of victims. On the one hand, they are exposed to a higher risk for injury or fatality than normal. However, these impacts lack data input.[113] More generally, the life quality is reduced as victims lack ability to decide freely over their life, incur threats, and other mental stress. Finally, the victims are financially exploited.

Both mental and financial impacts per victim of forced labor are quantified in this approach. While the mental health impact is uniform across the world, the financial exploitation impact depends on country- and sector-specific income levels. The two impact dimensions are added together, yielding a country-sector-specific impact in USD per forced labor victim.

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[108] OECD (2019): OECD.stat Pensions at a glance 2019. https://stats.oecd.org/Index.aspx?DataSetCode=PAG.

[109] International Social Security Association (2021): Country profiles – pensionable ages. https://ww1.issa.int/country-profiles/pensionable-ages.

[110] Pension Watch (2018): Social Pensions Database. http://www.pension-watch.net/social-pensions-database/social-pensions-database--/.

[111] ILO & UNICEF (2021): Child Labour: Global estimates 2020, trends and the road forward. https://www.ilo.org/ipec/Information-resources/WCMS_797515/lang--en/index.htm.

[112] ILO & Walk Free Foundation (2017): Global estimates of modern slavery: forced labour and forced marriage. https://www.ilo.org/wcmsp5/groups/public/@dgreports/@dcomm/documents/publication/wcms_575479.pdf.

[113] Vionnet, S.; Friot, D.; Haut, S.; Adhikari, R. (2021): Screening for human rights impact in corporate supply chains. A methodological proposal for quantitative assessment and valuation — Novartis case study. Working Paper. https://www.valuingnature.ch/post/measuring-human-rights-impact-in-corporates-supply-chains.

Impact Pathway

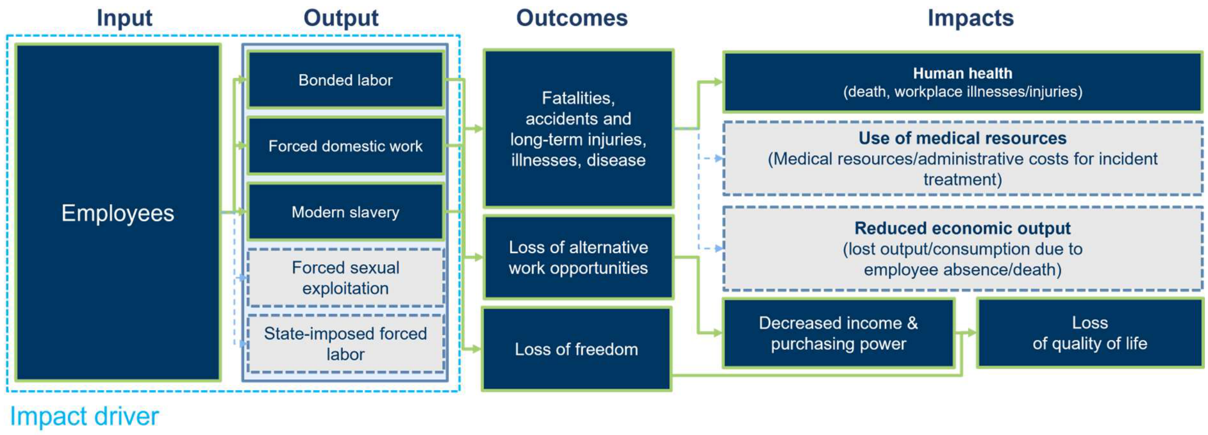

Figure 12: Impact pathway of Forced labor

Assumptions

We do not account for the costs of medical resources due to the human health impairment. Reduced economic output due to the physical and mental interference is also not considered. We only focus on the direct impact on human health and on the loss of wellbeing as described in the impact pathway above. The estimates for unduly withheld wages are built on local income levels. To make the impact on the life of the individual more comparable, we apply a purchasing power parity conversion.

Valuation approach

A) Mental health impacts

Several studies document the mental health impacts of life in forced labor circumstances. For example, Oram et al.[114] find that around 70% of in their sample of survivors of human trafficking in England suffer from depression, anxiety, or posttraumatic stress disorder (78% of women and 40% of men). In a study on bonded laborers in South-Eastern Nepal, the Freedom Fund[115] finds that more than 60% of their sample reported clinically significant depression symptoms, 46% clinically significant anxiety symptoms, and 47% some level of suicidal intentions.

To value the mental health impact of forced labor, we evaluate the quality-of-life reduction through the experience of psychological distress by translating it into DALYs. The Global Burden of Disease Collaborative Network[116] provides standardized "disability weights" that reflect the relative severity of a health state. The disability weight of a moderate episode of a major depressive disorder is chosen as comparative impact on the quality of life as life in forced labor. The characterization states that a person "has constant sadness and has lost interest in usual activities. The person has some difficulty in daily life, sleeps badly, has trouble concentrating,

[114] Oram, S.; Abas, M.; Bick, D.; Boyle, A.; Frenche, R.; Jakobowitz, S.; Khondoker, M.; Stanley, N.; Trevillion, K.; Howard, L.; Zimmerman, C. (2016): Human Trafficking and Health: A Survey of Male and Female Survivors in England, in: American Journal of Public Health (AJPH), Vol. 106, Nr. 6, pp. 1073- 1078.

[115] The Freedom Fund (2017): Understanding the psychosocial and mental health needs of bonded labourers in south-eastern Nepal, Evidence in Practice (2).

[116] Global Burden of Disease Collaborative Network (2020): Global Burden of Disease Study 2019 (GBD 2019) Disability Weights. Seattle, United States of America: Institute for Health Metrics and Evaluation (IHME), 2020.

and sometimes thinks about harming himself (or herself).” The assigned disability weight is 0.4.

This results in the following equation for valuation of the mental health impacts per person in forced labor:

$$\frac{0.4 * DALY}{case} * 200{,}000 \frac{USD}{DALY} = 80{,}000 \frac{USD}{case}$$

Note that this approach only covers the impacts for one year lived in a forced labor situation. Long-term consequences are not covered. The time frame is to be extended in the future to cover the mental health impacts more comprehensively. Further, the effects on mental health may depend on the type of forced labor endured. The loss of life quality may thus be further differentiated by adjusting the reference disability weight if details about the impacts are known.

B) Unduly withheld income

Several stakeholders incur negative impacts through the underpayment of forced labor victims:

- The victims lose earnings due to wage retention, debt repayments, and wage underpayment.
- The country where forced labor occurs fails to receive taxes due to undeclared incomes or the illegal nature of jobs.
- The country of origin of the forced laborers has lower remittances.

The International Labor Organization[117] has estimated profits made through forced labor for non-domestic and domestic forced labor.

B1) Non-domestic forced labor

The International Labor Organization (ILO) provides estimates for annual profits per victim in non-domestic private forced labor.[118] It distinguishes the sectors “Agriculture” and “Other Sectors” and by world region.

It also provides monthly average earnings per victim in these categories, allowing to calculate the share of income that is withheld from the victim:

$$regular\ income\ =\ profit\ per\ victim\ +\ 12 * monthly\ average\ earning$$

$$withheld\ income\ share = \frac{profit\ per\ victim}{regular\ income}$$

The above calculation yields withheld income shares of 30% to 90% depending on sector (agriculture/other) and region.

To value the economic losses incurred through forced labor, we apply these estimates to the average labor compensation in the sector in which forced labor victims are working, given by the reference Input-Output table.

[117] ILO (2014): Profits and Poverty: The Economics of Forced Labour. ILO Working Paper. https://www.ilo.org/wcmsp5/groups/public/---ed_norm/---declaration/documents/publication/wcms_243391.pdf.

[118] Ibid.

$$withheld\ income\ of\ a\ forced\ labor\ victim$$
$$= withheld\ income\ share\ * average\ sectoral\ labor\ compensation\ per\ employee$$

Due to lack of sectoral differentiation, we assume that the share of value added retained is the same across all economic sectors, except for agriculture and domestic work. In addition, rates are assumed to be the same for the countries within the regions for which data is provided by ILO.

B2) Domestic labor

"The economic data stored in the 2012 Global Estimate database of reported cases of forced labor show that, on average, domestic workers in forced labor are deprived of 60 per cent of their due wages"[119] i.e., wages they should or would earn if working freely in the corresponding regions. Therefore, the societal cost per victim in the sector covering households as employers is estimated as 60% of the per capita labor compensation in the sector, given by the reference Input-Output table.

4.2.4 Training

Overview

The total societal value created by corporate training is the accumulated increase in economic productivity of the person trained until her retirement through the training hours provided in a given year.

The estimation is based on the country-specific rate of return for *one year of* schooling, i.e., the percentage increase of income per year of schooling. These are scaled to the rate of return for one *hour* of schooling. The rate of return per school hour is multiplied with country- and sector-specific labor productivity, estimated by GDP per capita. Assuming that these productivity gains through training occur not only in the first but persist throughout the remaining work years, we calculate the net present value for all future income-earning years. These are estimated as the time to retirement age for a worker at the median age of employees in a country. The net present value of the absolute return per hour can then be multiplied with the number of training hours provided.

We follow capital perspective on training. By training its employees, a company increases its stock of human capital. This stock will be use in the following years, whether employees leave or stay at the company. It thus has the form of own work capitalized. It is similar to material stocks of capital created for the company's own use, for example a machine or building constructed used for production. The net present value of future productivity of such material capital stocks is accounted in balance sheets and discounted in future years as it is used up. The same logic can be applied to the stock of immaterial capital, like human capital through training.

Impact Pathway

Figure 13 describes the impact pathway of training. We do not consider the outcome which is associated with individual improvements like increase self-confidence as those properties are difficult to measure. Instead we focus on increased knowledge and skills which results in higher future income of employees. Social benefits of education like increased social and civic engagement are out of scope. Increased profits and lower operating costs are already covered by the economic indicators.

[119] Ibid.

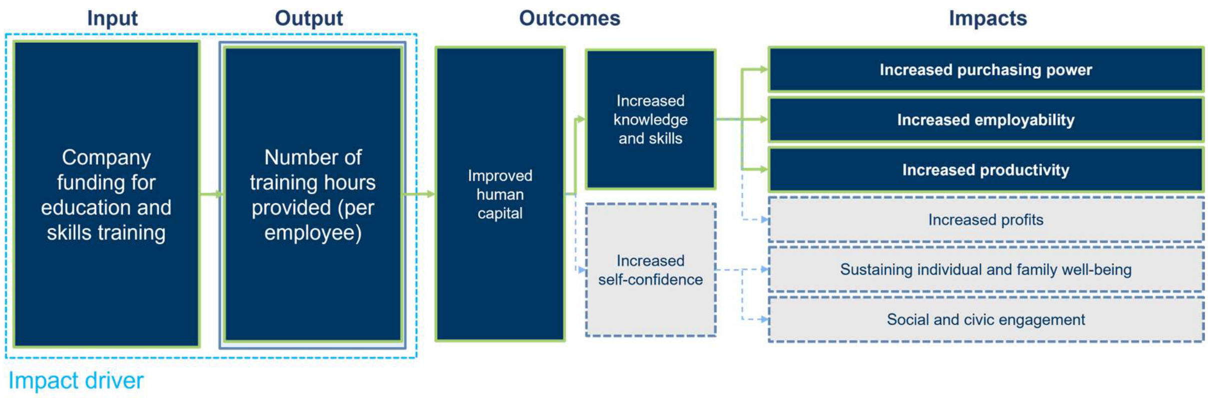

Figure 13: Simplified impact pathway of training

Assumptions

The key assumption is that productivity returns from corporate training are comparable to returns-to-income from schooling. There are two assumption levels. First, it is assumed that the effects of an hour of the two types of education are comparable. As there are no reliable estimates specific to corporate training that would allow an application across sectors and countries, this is the best available guess. Second, the return-to-schooling estimates reflect increases in *income*. Income gains could also be driven by reputational or other factors connected to education besides increases in productivity (e.g., due to knowledge or efficiency gains). The influence of other factors might also depend on the level of schooling. Nonetheless, considering that income increases at a lower rate than productivity at the level of economies or sectors, income returns to education are a reasonable proxy for productivity returns.

In addition, the rate of returns to training are specific to a country but assumed constant across sectors. Yet, we use sector-specific productivity values. Although the relative increase in productivity per hour of training is thus constant across sectors, the absolute value depends on the general level of productivity.

The net present value is calculated with a 1.5% discount rate.

Valuation approach

A) Returns to schooling

The most recent source on income returns to a year of schooling is provided by Psacharopoulos & Patrinos.[120] There are two main methods to estimate the return to education: a) the Mincerian method, where private return estimates to education overall are available, and b) the full discounting method, distinguishing returns to different levels of education.

Where available, the Mincerian estimates are preferred. For other countries, full discounting estimates for secondary and higher education are chosen, as corporate training generally does not aim to provide fundamental skills like primary education.

The returns to one year of schooling are scaled to an hour of schooling using the hours of instruction per school year. OECD[121] provides data on the average hours per year of intended

[120] Psacharopoulos, G. & Patrinos, H.A. (2018): Returns to Investment in Education. A Decennial Review of the Global Literature. World Bank Policy Research Working Paper 8402. https://openknowledge.worldbank.org/handle/10986/29672.

[121] OECD (2019a): Education at a Glance 2019: OECD Indicators, OECD Publishing, Paris, https://doi.org/10.1787/f8d7880d-en .

instruction time in lower secondary education. If unavailable, compulsory instruction time is taken. As second source we use Nationmaster[122], providing the intended hours of instruction per year for 13-year-olds in public educational institutions. This yields data for 53 countries. For the remaining 135 countries, we use the average of the regional and income group averages for the respective country (country categories as defined by the world bank).

B) Productivity

Data on productivity is taken from the WifOR input output table which combines the WIOD and EORA multiregional input-output databases. The societal value of one hour of training is performed for each country-sector, using the gross value-added values.

C) Remaining work life

To estimate the accumulated productivity gains, we calculate the number of remaining work years for an employee at the median age of the workforce. The main benchmark is the number of years this median-aged worker has left until they reach the country's official retirement age.

The median age of the workforce is provided by ILO.[123] Values for missing countries are estimated using the average of the region and income averages. The retirement age is estimated combining four sources in the following order, depending on availability:

- OECD[124], providing the current retirement ages for a person who entered the labor force at age 22 (general or men if differentiated by gender),
- International Social Security Association[125], collecting the statutory pensionable age,
- the 'Social Pensions Database' by Pension Watch[126], providing the Age of eligibility for social pension scheme,
- and individual research for the remaining countries.

For some countries, the official retirement age, however, lies above the life expectancy of a person that is of the median age of the workforce. Life expectancy at birth, i.e., the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life, is drawn from the WDI Indicators Database.[127] Where official retirement age is less than 5 years higher than the life expectancy of a person at the median age of the workforce, we take 5 years off the average life expectancy to approximate the end of working life.

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[122] Nationmaster (2000): Hours of instruction for pupils aged 12. https://www.nationmaster.com/country-info/stats/Education/Hours-of-instruction-for-pupils-aged-12.

[123] ILO (2019): Median age of the labour force by sex -- ILO modelled estimates, Indicator EAP_2MDN_SEX_NB. Estimates for 2019.

[124] OECD (2019b): OECD.stat Pensions at a glance 2019. https://stats.oecd.org/Index.aspx?DataSetCode=PAG.

[125] International Social Security Association (2021): Country profiles – pensionable ages. https://ww1.issa.int/country-profiles/pensionable-ages.

[126] Pension Watch (2018): Social Pensions Database. http://www.pension-watch.net/social-pensions-database/social-pensions-database--/ .

[127] WDI Indicators database (2021b): SP.DYN.LE00.IN: Life expectancy at birth, total (years).

Formula

We calculate the effects of one hour training with the following formular:

$$\sum_{j=1}^{n}\sum_{i=0}^{m}\frac{\theta_j * t_j}{(1+\beta)^i} * v_{j,s}$$

with $m = \min\left((p_j - a_j); \left(l_{j,a_j} - 5 - a_j\right)\right)$

and $\theta_j = \frac{\alpha_j}{h_j}$

$\theta_j = training\ coefficient\ (estimated\ return\ rate\ to\ 1\ hour\ of\ training)$

$\alpha_j = return\ rate\ to\ 1\ year\ of\ schooling\ in\ country\ j$

$h_j = school\ hours\ per\ school\ year\ in\ country\ j$

$t_j = number\ of\ training\ hours\ provided\ in\ country\ j$

$m = average\ work\ years\ after\ training$

$p_j = official\ retirement\ age\ in\ country\ j$

$a_j = average\ age\ of\ employees\ in\ country\ j$

$l_{j,a_j} = life\ expectancy\ at\ average\ age\ of\ employees\ in\ country\ j$

$v_{j,s} = GVA\ per\ employee\ (upstream:\ in\ sector\ s\ of\ country\ j)$

$i = [0; m]\ time\ periods\ during\ which\ training\ benefits\ occur$

$j = countries\ in\ which\ training\ is\ conducted$

$\beta = discount\ rate$

4.2.5 Fair wages

Overview

The fair wages indicator challenges the assumption that every job has a positive impact on the society. It assesses the quality of employment by valuing the wages paid to employees. Specifically, the health utility of income is measured i.e., the contribution of income to an individual's wellbeing in terms of disability-adjusted life years (DALYs) gained. The following describes the WifOR-adjusted implementation of the approach developed by Valuing Nature.[128,129]

A wage threshold is introduced against which wages are evaluated. The 'living wage' is a wage that allows a basic but decent level of life, taking local circumstances into account. Employees paid below the living wage cannot maintain a basic but decent level of life despite their work. Their employment condition thus leads to negative effects for their quality of life which reduce the life expectancy. Wages below the living wage therefore have a negative impact on life expectancy, wages above the living wage have a positive impact on life expectancy.

The health utility of income (HUI) factors indicate by country how many disability-adjusted life years (DALYs) are gained per USD of income. Thereby, the difference of wages to the living wage is translated into DALYs gained or lost, depending on whether wages are above or below the living wage. The DALYs are then valued at 200,000 USD following the standardized WifOR approach (compare chapter 3.3). The valuation of DALYs differs from the approach suggested by the original authors, who applied a "productive value of life" approach. The basic approach is thus as follows:

$$(wages\ paid - living\ wage) * HUI\ factor = DALYs\ gained\ or\ lost$$

$$DALYs\ gained\ or\ lost * 200{,}000\frac{USD}{DALY} = social\ value\ created\ or\ lost$$

The calculation is slightly modified, as the impact of an additional income unit on health depends on the amount of income: the law of diminishing marginal utility of income suggests that the benefit gained from an additional unit of income decreases as income increases. At wages close to the living wage, higher wages allow large improvements regarding diet, exercise and education and thus larger health and life expectancy improvements. The higher the wage, the smaller the improvements in this regard through additional income. We provide two different approaches to depict this divergence between the benefits of additional income depending on the income level. They are described below.

[128] Vionnet, S. & Haut, S. (2018): Measuring and valuing the Social Impact Of Wages – The Living Wages Global Dataset And The Health Utility Of Income. Working Paper.

[129] Vionnet, S.; Adhikari, R.; Haut, S. (2021): The Health Utility of Income and Taxes. Part A - Health Utility of Income. Impact valuation methodology, global assessment and application to businesses. Whitepaper, Valuing Impact. https://www.valuingnature.ch/post/the-utility-of-income-and-taxes .

Impact Pathway

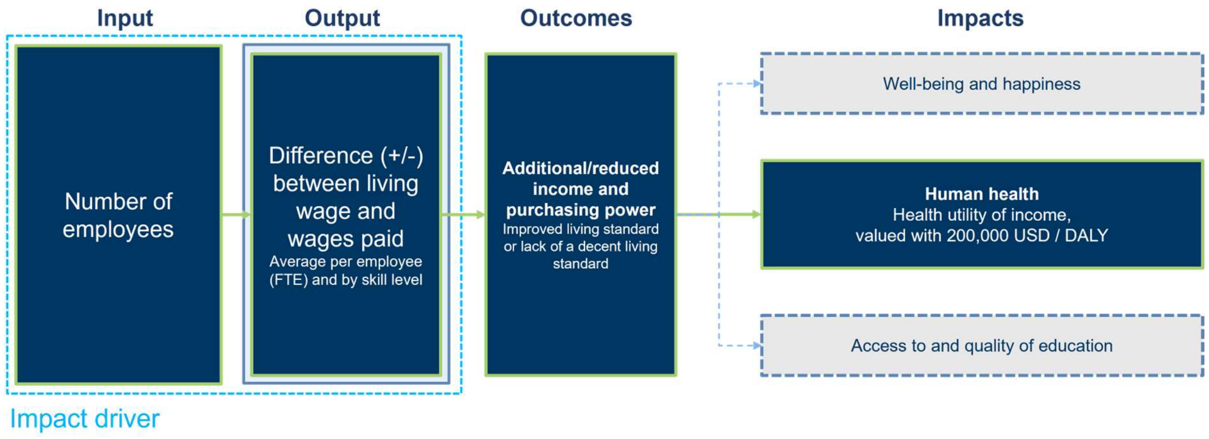

Figure 14: Simplified impact pathway fair wages

Assumptions

Based on the law of diminishing marginal utility of income, we assume that a higher income is associated with lower growth in satisfaction per additional unit of income. We have two different approaches to model the different utility effects of additional income.

Following the first approach, we value each income unit difference from the living wage at the same rate, disregarding if it is below or above the baseline. But we set a cutoff point at an income of four times the living wage in each country. Above this threshold, no additional income is valued. In this case, the assumption is that for people with an income at or above the threshold of four times the living wage, any additional income has no effect on their wellbeing whatsoever.

In the second approach, we model the decreasing marginal utility of income. As there is no specific data on the wellbeing effect of additional income for different income levels, we assume them, following the originally suggested approach for marginal HUI factors as described by Vionnet and Haut,[130] as shown in Table 10.

Wage level	Below LW	LW	Up to 2 LW	Up to 3 LW	Up to 4 LW	Up to 5 LW
% of HUI to consider	-100%	baseline	100%	50%	30%	20%

Table 10: HUI values following Vionnet & Haut (2018).

Incomes are split into six groups relative to the respective living wage in each country. For incomes below the living wage and up to two times the baseline, the full HUI is considered. Above that, additional income is weighted less in the monetarization, as Table 10 shows. Above a certain threshold (here five times the living wage), additional wages are assumed to no longer provide an additional health benefit. The societal value of wages exceeding five times the living wage is thus the same as the value of five times the living wage.

Valuation approach

A) Living wages

The living wages reflect a wage that allows a basic but decent life, considering local contexts. The living wage usually includes the cost of food, housing, health, and education, as well as

[130] Vionnet, S. & Haut, S. (2018).

other necessary basic spending (e.g., transport, communication, etc.) and reserve for unexpected events. It is calculated accounting for different family situations, particularly in terms of the number of kids and working parents. We used a data set provided by Vionnet.[131] This data uses estimates for a typical family. The living wage is country-specific and does not differentiate by region within the country. Missing countries in the set were estimated using the mean of the corresponding World Bank income group.

B) Health Utility of Income (HUI)

The HUI factors indicate how many disability-adjusted life years (DALYs) are gained per USD of income. For a description of the approach see Vionnet et al..[132] The HUI factors for 2018 were provided per country by Valuing Nature. Missing countries in the data set were estimated using the mean of the World Bank income Group.

4.2.6 Gender pay gap

Overview

The indicator values impacts arising from gender inequality expressed in terms of the differences in earnings between men and women (i.e., gender pay-gap). In countries with a high gender pay imbalance women hold a lower societal status. This unequal distribution of income and hence wealth ultimately poses barriers to access healthcare.[133,134] The resulting health impact is estimated in Disability Adjusted Life Years (DALYs).

Impact Pathway

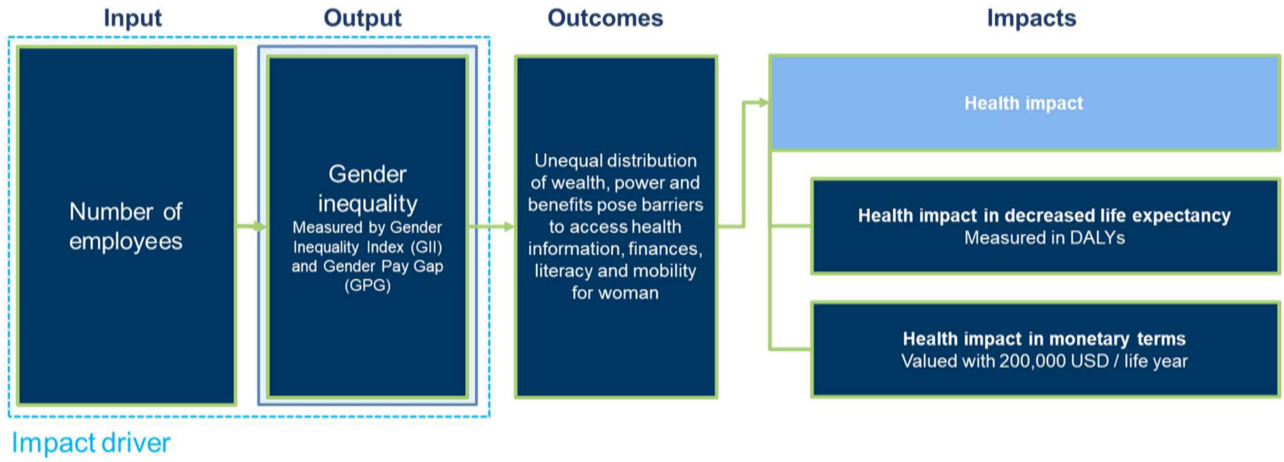

Figure 15: Impact pathway gender pay gap

[131] Vionnet, S. (2020): A worldwide living wage dataset for benchmarking compensation practices in global value chains. Technical Paper. Valuing Nature. https://www.valuingnature.ch/post/living-wage-world-dataset

[132] Vionnet, S.; Adhikari, R.; Haut, S. (2021): The Health Utility of Income and Taxes. Part A - Health Utility of Income. Impact valuation methodology, global assessment and application to businesses. Whitepaper, Valuing Impact. https://www.valuingnature.ch/post/the-utility-of-income-and-taxes.

[133] Jafar Hassanzadeh, Noorollah Moradi, Nader Esmailnasab, Shahab Rezaeian, Pezhman Bagheri, Vajihe Armanmehr (2014): "The Correlation between Gender Inequalities and Their Health Related Factors in World Countries: A Global Cross-Sectional Study", *Epidemiology Research International*, vol. 2014, Article ID 521569, 8 pages, 2014. https://doi.org/10.1155/2014/521569

[134] Pinho-Gomes A, Vassallo A, Carcel C, et al. (2022): Gender equality and the gender gap in life expectancy in the European Union, BMJ Global Health 2022;7:e008278.

Valuation approach

Gender inequality is commonly expressed using the gender inequality index (GII). Vaes et al.[135] analysed the link between gender inequality (GII) and health indicators (e.g., DALYs) between 1990 and 2017 for 36 OECD countries. The study concluded that a 0.1 unit increase in GII, leads to 0.05 years decrease in life expectancy of a person (see figure 16). The relationship between the GII and the GPG was calculated by using GII and GPD data of 48 countries. The analysis concludes that a 0.1 unit increase in GPG (10%), correlates with a 0.04 unit increase in the GII (see figure 17). By bringing the above together it can be concluded that a 10% GPG, is correlated with a 0.2 years decrease in the total life expectancy of a person, a GPG of 15% to a 0.3 years life expectancy decrease, accordingly. The decrease in life expectancy is translated into DALYs with 1 DALY being valued at 200,000 USD (compare chapter 3.3).

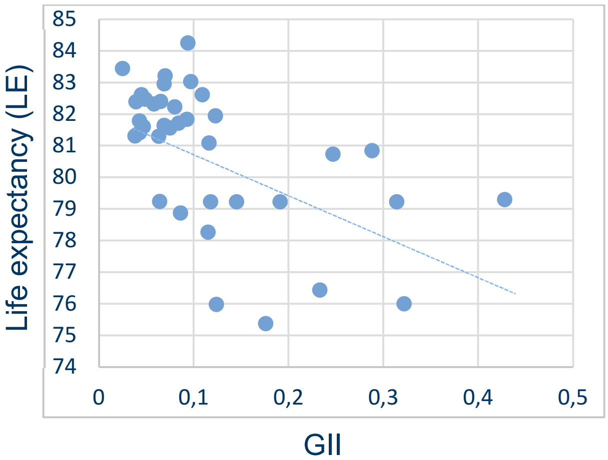

Figure 16: Correlation of GII and LE following Vaes et al.[136]

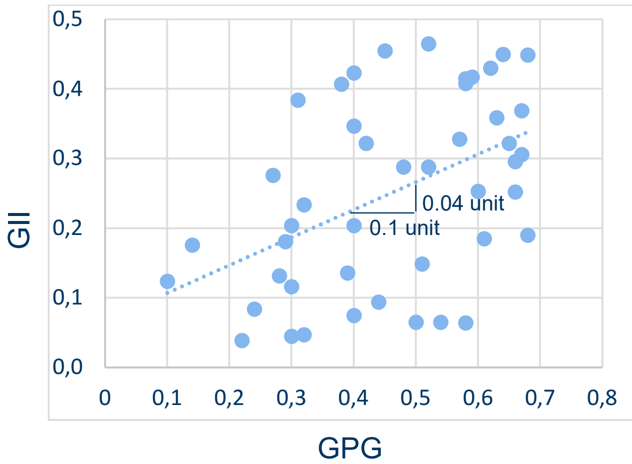

Figure 17: Correlation between GII and GPG done by WifOR

A) Gender Pay Gap

The GPG data is expressed in percentage, i.e., how much less or more women earn in a respective sector and country compared to men. This ratio is derived by connecting the mean monthly earnings of employees by gender and economic activity from ILOSTAT[137] with the absolute number of employees split by male and female per economic activity from Exiobase 3.[138]

B) Gender Inequality Index (GII)

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[135] Vaes et al. (2021): Association between gender inequality and population-level health outcomes: Panel data analysis of organization for Economic Co-operation and Development (OECD) countries. *The Lancet*, Volume 39, 101051.

[136] Vaes et al. (2021): Association between gender inequality and population-level health outcomes: Panel data analysis of organization for Economic Co-operation and Development (OECD) countries. The Lancet, Volume 39, 101051. https://doi.org/10.1016/j.eclinm.2021.101051.

[137] ILO (International Labour Organisation) (2018). *Global Wage Report 2018/19: What lies behind gender pay gaps.* https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_650553.pdf .

[138] Stadler, K., R. Wood, T. Bulavskaya, C.J. Södersten, M. Simas, S. Schmidt, A. Usubiaga, J. Acosta-Fernández, J. Kuenen, M. Bruckner, S. Giljum, S. Lutter, S. Merciai, J.H. Schmidt, M.C. Theurl, C. Plutzar, T. Kastner, N. Eisenmenger, K.H. Erb, A. de Koning and A. Tukker. (2018): EXIOBASE 3: Developing a time series of detailed Environmentally Extended Multi-Regional Input-Output tables. Journal of Industrial Ecology.

The United Nation's indicator for measuring gender inequality, the GII[139] depicts three dimensions as measurements for inequality among men and women: reproductive health, empowerment, and the labour market. The GII ranges from 0 to 1, where a low value of the GII indicates low inequality between women and men and vice-versa.

Assumptions

- The average number of working years is set to 35.6 years to estimate the health impact of the GPG.[140]
- The average life expectancy used is 72.7 years, which is the average life expectancy at the global level.[141]
- The GII has a linear relationship with GPG as long as no other impacting parameters are considered.
- Life expectancy has a linear relationship with the GII as long as no other impacting parameters are considered.
- This approach is based on a binary view on gender. Employees are assigned to one of two possible genders (male/female). Non-binary employees are not considered.

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[139] UNDP (United Nation Development Program) (2020): Technical notes, Human Development Report 2020. https://hdr.undp.org/system/files/documents//technical-notes-calculating-human-development-indices.pdf.

[140] Eurostat (2022), Dataset: Duration of working life; Data Code: LFSI_DWL_A. https://ec.europa.eu/eurostat/databrowser/view/lfsi_dwl_a/default/table?lang=en.

[141] World Bank (2020), Life Expectancy at birth, total (years). https://data.worldbank.org/indicator/SP.DYN.LE00.IN.

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