METHODOLOGICAL REPORT

WifOR Impact Valuation

Underlying valuation approach, assumptions, and extrapolation.

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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 for companies and sectors. In the absence of publicly available, regionalized valuation factors for both environmental and social impacts, WifOR has developed a set of value factors for a range of environmental and social indicators and recommends their usage until a global standard is established. WifOR decided to publish the value factors and the underlying methodology to promote transparency and as a consequence, public discussion about valuing non-financial impacts. As impact valuation seeks to compare diverse impact areas in monetary terms, this involves a number of ethical considerations and underscores the strong need for standardization.

Currently, several approaches to impact valuation exist, often differing considerably. The divergence of different monetization factors might give the impression that results are arbitrary and non-reliable for strategic decision-making. To counteract these concerns, a standardization of impact valuation should be the long-term goal. However, achieving this standardization requires collaborative input from a broad group of stakeholders rather than decisions made by a single institution. Publication of factors and methodology is a step forward to increase stakeholder dialogue and building trust in the methodology. While a final consensus on the exact methods of impact valuation may be challenging, especially with unresolved ethical considerations, this is not a fundamental issue for the methodology itself. Results can still be transparently understood within the context of these ethical choices (a common example is the different valuation of GHG emissions depending on the valuation of future generations).

The authors recognize that advancing academic research and data availability will require ongoing updates to valuation factors. Future changes to the valuation are unavoidable, due to its innovative character and the rapid development of impact valuation in general. Likewise, new value factors are constantly being developed and included in the WifOR valuation framework.

This document is structured as follows: Chapter 2 describes the general concept of impact valuation, including its scope of application. Chapter 3 details WifOR’s methodology. Chapter 4 outlines the Value to Society perspective, presenting the indicator indicator documentations across the environmental and social domains. Each indicator documentation is structured into an overview part, an impact pathway, the description of the valuation approach and some highlighted assumptions. Chapter 5 describe the Value to Business perspective, detailing how societal and environmental impacts translate into corporate risks and opportunities—currently exemplified through the climate-related risk indicator. Finally, Chapter 6 lists all data sources used in the development of this methodology.

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, recognizing, understanding and ultimately managing the multiple impacts economic actors have on society is crucial. Assessing and reporting on impacts is the first step to approaching this challenge. Traditionally, 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 advances two steps further: First, it records the environmental and social changes triggered by these outputs and traces their impacts on society. Second, these impacts are translated into monetary values. This unified metric then enables comparison of a wide range of traditionally reported output indicators.

	Impact	x	Value factor	=	Monetized impact
Example GHG:	CO2e in t	x	Societal costs per t CO2e	=	Societal costs of CO2 emissions

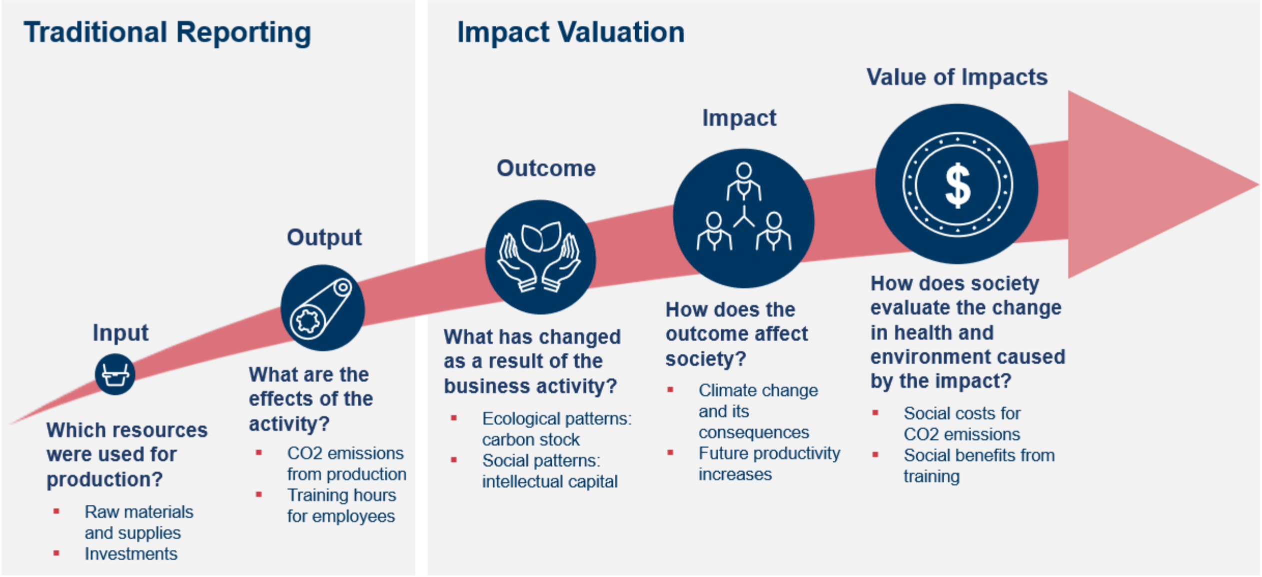

Figure 1: General approach to monetize impacts (adapted from Value Balancing Alliance e.V. 2021)

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 entirely objective.

2.2 Scope of application

The scope of impact drivers considered in this methodology spans the three core dimensions of sustainable business practice: economic, environmental, and social. A meaningful societal impact assessment acknowledges that a company’s influence on these dimensions extends beyond areas of direct financial or operational control. Through global procurement, companies generate indirect impacts associated with the production of purchased goods and services, directly at the supplier and further up the supply chain. Similarly, the design of products and services affects customers use and disposal, resulting in further indirect impacts to society. This methodology is intended for application across an organizations full value chain, 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, which focuses on the positive and negative impacts of corporate activities on the environment and society – the *value to society* perspective; and a financial-driven view, which focuses on the consequences of these impacts (and dependencies) on the corporate financial performance of corporations – known as the *value to business* perspective. Both perspectives are inherently connected and have, thus, been widely acknowledged as “double materiality” (Accountancy Europe 2020; Climate Disclosure Standards Board (CDSB) 2020; European Commission 2019). This methodology adopts the *value to society* perspective, and aims to reflect the broader impact that businesses have on their environment and society at large.

There are different approaches to measure *value to society*, with the choice depending on the area of application and purpose of the analysis. The two most prominent approaches are based on the estimation of (1) abatement costs and (2) damage costs. Abatement costs reflect the expense of avoiding specific impacts, e.g., conservation funds to prevent the decline of biodiversity. Damage costs reflect the expense of impacts that already occurred, often including costs to human health, life quality, or economic losses. At WifOR, indicator valuation primarily reflects damage costs; however, 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 the valuation of specific indicators can be found in the respective documentation (see section 4).

Another key aspect considered in the valuation framework is that the societal impact of an impact driver depends on the local social and environmental context in which it occurs. To account for this, country specific value factors have been developed for 188 countries. These local values recognize, e.g., that draining water resources has more serious health effects in locations with higher water scarcity. The special adjustments of monetization factors is detailed in the respective indicator documentations (see section 4). Exceptions to this approach 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 4.1.3). A similar consideration is valid for marine plastic leakage (see 4.1.5).

3.2 The valuation of losses in the future

Many social and environmental effects manifest not only in the present, but also extend into the future. To comprehensively assess the effects of corporate activities, it is essential to account for impacts on future generations. In economics, discounting is standard approach to convert future costs and benefits into their net present value.

Discounting can be motivated by the fact that (1) individuals tend to prioritize the present over the future, (2) consumption growth is expected in the long run, making a unit of wealth less valuable in the future than it is today, and (3) 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 (Ramsey 1928):

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

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 sets a practical limit on 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 selection 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 (Umweltbundesamt 2012), assuming a long-term growth rate of g=1.5% (World Bank 2022) and η=1. The pure time discount rate reflects ethical choices regarding 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, consistent with the notions of intergenerational equity prevalent in the climate change literature. The exceptions of this rule should be clearly labelled. Unless stated otherwise, this results in a social discount rate of 1.5%.

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 within and beyond impact valuation research. Whenever a decision impacts human lives, the trade-offs between options must be weighed against each other – implicitly assigning a value to human lives in the process. In impact valuation, this value is made explicit, which both enables and necessitates a debate about this fundamentally ethical consideration.

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 often used in policy making to assess whether the benefits of regulations that lower mortality risk justify their implementation costs. As this approach considers the perspective of the people affected, the WifOR valuation method applies a VSLY approach.

VSLY estimates depend on the country, population age, wealth level, and assessment method (Schlander et al. 2017). While the WHO recommends a magnitude of 1-3 times the gross domestic product (GDP) per capita, several studies argue for a higher estimate, citing empirical studies between 3.5 and 6.5 times the GDP per capita (Trautmann et al. 2021; Robinson et al. 2017). For instance, Schlander et al. (2017)) 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, a consistent VSLY is applied globally 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 to 200,000 USD in order not to feign false accuracy. This value is thus at the higher end of VSLY estimates.

3.4 Standardization among indicators

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

Time: All value factors are expressed in current USD. If the source only specifies the value factor for a specific year, we apply a deflation rate to obtain the current USD of the respective year. To do so, GDP deflator values from the World Bank are applied.

PPP adjustment: If an impact occurs locally and is directly affecting people, values are adjusted for purchasing-power-parity (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 0 for more information.

Valuation of human life: For indicators that include the loss of life years or 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, as different impact drivers can follow the same or similar impact pathways. This issue is especially relevant when analyzing several indicators simultaneously. For example, waste incineration releases air pollutants that contribute to respiratory diseases, resulting in health costs. These costs are embedded in the “waste” factor but are also integrated in the “air pollution” factor. Subtracting this impact from the waste factor would underrepresent the impact of waste, while adding the impact of both indicators is subject to double counting.

Caution should also be exercised with indicators that vary in granularity. For instance, 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) overlap, as PM2.5 is a subset of PM10. However, the smaller particles have a graver effect on human health and are hence assigned a higher cost and shown separately.

3.6 Netting impacts

Impact valuation aims to increase transparency, which it cannot fulfil if results are presented at a highly aggregated level. While expressing different impacts in a common metric reduces complexity, it comes at the cost of cancelling out nuances. This simplification can be helpful but should not imply that negative impacts can be offset by positive ones. There are cases where netting impacts is appropriate (e.g., netting an indicator across locations), while there are applications (e.g., netting across different indicators) that pose the risk of green-washing and communicating distorted results. In the current state of impact valuation, limitations such as overlapping indicators (double counting), varying valuation approaches and a lack of data to fully picture impacts, are still present. Furthermore, different impacts affect different groups, so a positive impact for one group does not compensate for negative impacts on another (e.g., extra vocational training for managers does not offset agricultural losses due to water scarcity). The authors therefore advise for a clearly distinguishing impact drivers and handling netting and the analysis of results with caution.

4 Value to Society - 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 Environmental indicators

4.1.1 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 (World Health Organization (WHO), n.d.). 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 when the emission source is closer to ground level and location in areas with higher population density. 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 (H. Matthey and Bünger 2019). A typical differentiation used in this context is between urban, peri-urban, rural, and transport environment.

Impact Pathway

The impact pathways of air pollution are summarized in 3. Human activities such as energy production and energy use, resource extraction and others are marked as inputs. The output of these activities are air emissions (marked in light blue). The air emissions monetized by WifOR are marked in dark blue 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 pollutants increases and air quality declines.

Reduced air quality leads to a multitude of effects. It affects human health directly by contributing to respiratory and cardiovascular diseases. Elevated particle concentrations also lower visibility, increasing shipping and aviation costs. Worsened air quality can 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. Environmental 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).

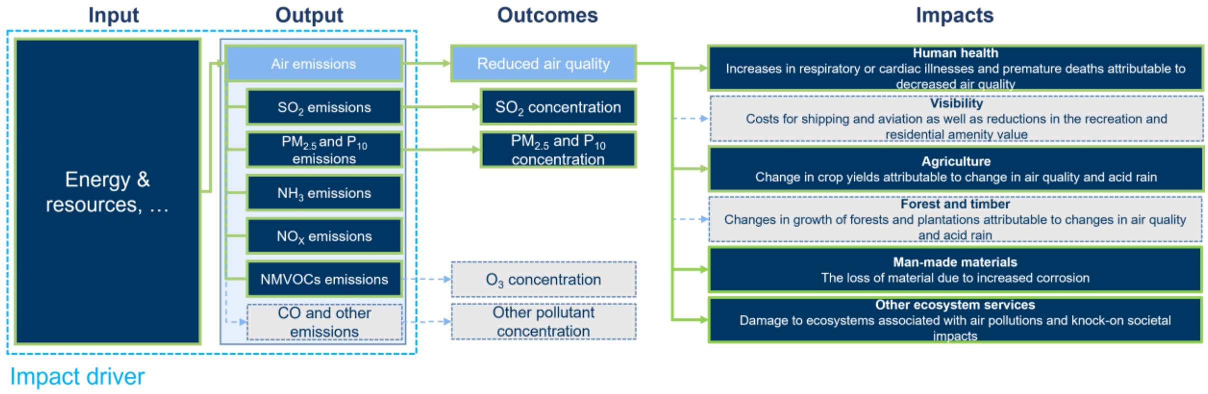

Figure 3: Impact Pathway of Air Pollution (source: own illustration)

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 societal damages related to (H. 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 (Preiss et al. 2008). According to NEEDS, health effects of air pollutants are determined based on data compiled from World Health Organization in 2013 which subsequently aligned with current EU standards (Holland 2014). Crop losses are determined based on the exposure-response relationship described by Mills et al. (2007). Where this was not possible, as for building/material damage and biodiversity losses, costs were determined using updated NEEDS data.

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

€$_{2016}$/t Emission	**Health damages**	**Biodiversity loss**	**Crop/harvest damages**	**Material/infrastructure damages**	**Total**
$PM_{2.5}$	58,400	0	0	0	58,400
PM_{10}	41,200	0	0	0	41,200
NO_x	14,400	2,600	800	130	17,930
SO_x	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 requires a range of adjustments and assumptions. If the emission source is unknown, we assume them to be released in a peri-urban environment, as this is the 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 (unknown, 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 2 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, Table 1: Average environmental cost of air pollution from emissions from UBATable 1 and Table 2 can be used to derive monetization factors for the total air emission 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. 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 (2022). 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 (4.1.2) 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 (World Bank 2020c). Germany is set as the baseline and values are scaled up- and down for more and less densely populated countries. All pollutants examined 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 (World Bank 2020a). We normalize these values relative 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.

4.1.2 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 (National Geographic Education 2022). The WWF's 2022 Living Planet Report estimates an average 69% decline in global populations of mammals, fish, birds, reptiles, and amphibians since 1970 (Almond et al. 2022). 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.*"

Impact Pathway

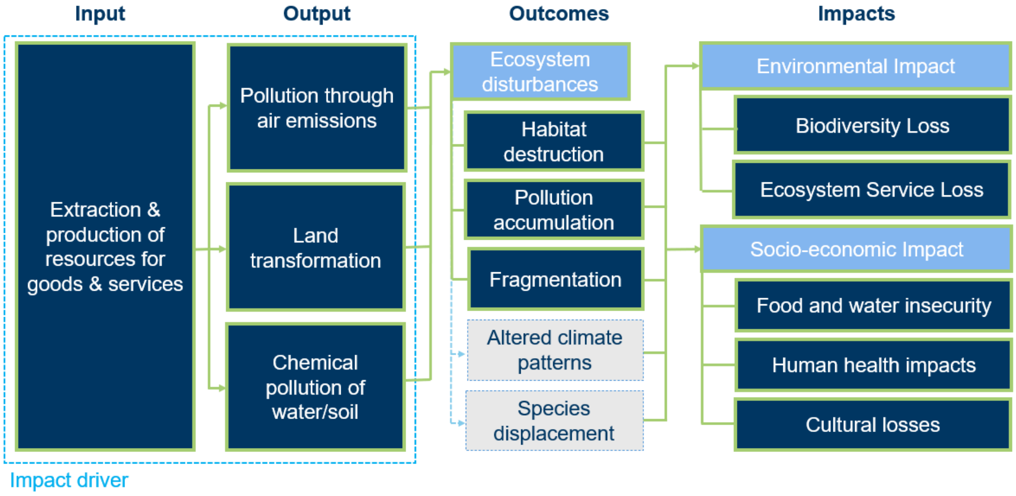

Figure 4: Simplified Impact pathway of Biodiversity (source: own illustration)

Figure 4 displays a simplified biodiversity impact pathway. The primary activities that cause ecosystem disturbances include those that contribute to pollution through air emissions, involve land transformation, or lead to chemical pollution of water bodies and soil. These activities result in key ecosystem disturbances, such as habitat destruction, pollution accumulation, and habitat fragmentation. The alteration of climate patterns and species displacement are likely only indirectly captured by this indicator due to the complexity of quantifying their impact and the current limitations in available research. Ultimately, the main environmental and socio-economic impacts of these ecosystem disturbances include biodiversity loss, degradation of ecosystem services, food and water insecurity, negative effects on human health, and cultural losses.

Valuation approach

While the impact pathway maps the chain of effects from human activities on ecosystems and beyond, the actual impacts themselves are not directly monetized. Instead, in “Monetary Valuation of Environmental Impact factors – Models and Data”, Steen (2020) developed a model to estimate impacts on biodiversity from single human activities using an abatement cost approach, which values biodiversity based on the cost of preventing its decline. His approach incorporates two steps.

First, the global share of species threatened by a specific human activity is divided by the total amount of this activity. The resulting number is called an environmental impact factor and it gives a share of (threatened) species per unit of the activity. In the case of some types of air pollution (such as, e.g., NH_3), the share of species threatened by NH_3 emissions is divided by the quantity of global NH_3 emissions in kg. In the case of land use, the share of species threatened by urban land use is divided by the m^2 of global urban land use. This impact factor is interpreted as the share of biodiversity conservation costs that is caused by one unit of the human activity under consideration (kg in the case of NH_3, m^2 in the case of urban land use, and so on).

Second, the environmental impact factor is multiplied with an estimate of the annual global biodiversity conservation costs to arrive at a global biodiversity impact value in monetary units per unit of the human activity under consideration.

We follow Steen’s framework and consider three 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). This abatement cost approach focusses on mitigating the central ecosystem disturbances caused by activities – centrally incorporating management costs of habitat preservation, pollution reduction, and restoring habitat connectivity.

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 (Deutz et al. 2020). We use the upper value to rather over- than underestimate impacts on biodiversity. Additionally, to avoid double counting, costs associated to invasive alien species (IAS), approximated at the upper bound at $84 billion per year, are excluded from the biodiversity price, as IAS costs are accounted for separately within the IAS indicator. Thus, the upper bound of the global biodiversity conservation costs is 967- 84 = $883 billion.

Environmental impact factors

Steen (2020) provides estimates of the 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. More details about threat causes for red-listed species can be found in IUCN's database (IUCN 2022).

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:

$$impact\ value_i = environmental\ impact\ factor_i\ *\ 8.83\mathrm{E}+11$$

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	7.12E-04
NOx	kg Nox	-2,23E-15	-1.97E-03
PM10	kg PM10	5,58E-14	4.93E-02
SOx	kg Sox	-3,93E-15	-3.47E-03
CH4	kg CH4	4,732E-15	4.18E-03
CO	kg CO	5,92E-16	5.23E-04
CO2	kg CO2	1,69E-16	1.49E-04
N2O	kg N2CO	4,48E-14	3.96E-02
NH3	kg NH3	1,30E-14	1.15E-02
Land use animal rearing	m^2year	3,33E-15	2.94E-03
Land use agriculture	m^2year	1,07E-14	9.45E-03
Land use forest	m^2year	2,00E-14	1.77E-02
Land use paved	m^2year	1,30E-13	1.15E-01
Nitrogen water pollution	kg N-tot	2,06E-14	1.81E-02
Phosphorus water pollution	kg P-tot	1,83E-13	1.62E-01

Table 3: Impact values of selected activities impacting biodiversity following Steen (2020).

Local adjustments

The sourced rates capture a global average. To adjust for local impacts, we assume that the number of threatened species per country, influenced by country size, correlates with the severity of biodiversity loss and associated costs. While it is likely that impacts are proportional to the number of threatened species in a country, some countries may be home to more threatened species simply due to larger country area. Therefore, we calculate a country-specific scaling factor based on each country's deviation from a predicted baseline that considers both threatened species counts and area. As done in Pyšek, P. et al.'s (2017) paper, a regression model using the log-transformed values of threatened species and country area establishes an expected number of threatened species for each country (Figure 5).

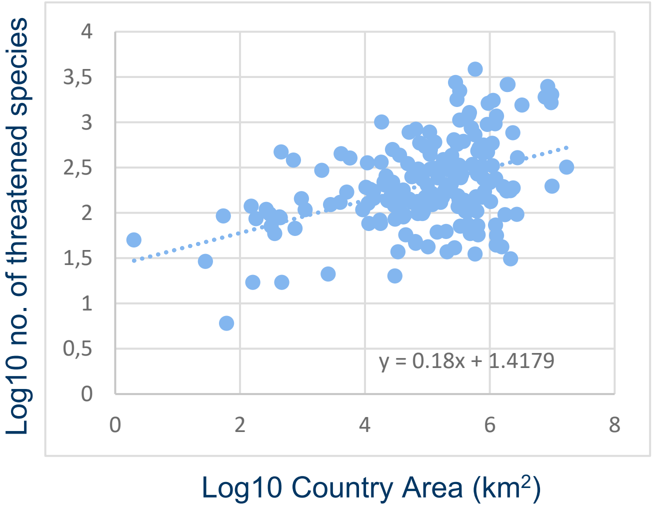

Figure 5: Logarithmic relationship between threatened species count and country area

The scaling factor is then calculated by dividing the actual by the predicted number of threatened species (based on country area only). This approach allows for an accurate valuation of biodiversity loss, accounting for variations in species count relative to country size.

$$Local\ scaling\ factor\ of\ country_i = \frac{recorded\ threatened\ species\ count\ in\ country_i}{predicated\ threatened\ species\ count\ in\ country_i\ based\ on\ area}$$

Data on red-listed species per country is sourced 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. Thus, if a country has the same number of threatened species as one would expect, taking its area into account, then its activities are valued at the global impact value. However, if a country has a higher number of threatened species than expected for its area, then it is also more densely populated by threatened species, which leads to a higher than average impact factor.

$$Impact\ value\ in\ country_i\ and\ activity_j = local\ scaling\ factor\ of\ country_i * global\ impact\ value_j$$

Future research

Steen (2020) further provides environmental impact factors: for Arsenic, Cadmium, and Mercury to freshwater. As of now, these are not included as physical data as 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.

4.1.3 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 groundwater resources (Meyer 2014). Greenhouse gases include various gases, whereby the most dominating ones are: Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2). Additionally, we consider so called F-gases which have a smaller overall impact on climate change but exhibit a very large impact per ton emitted.

GHGs are measured 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 sixth assessment report of the intergovernmental panel on climate change (IPCC). More specifically we use the following GWPs: CO_2: 1 CO_2e; CH_4: 29.8 CO_2e; N_2O: 265 CO_2e.

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 (A. Matthey and Bünger 2019; Anthoff 2007). 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. 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.

Impact Pathway

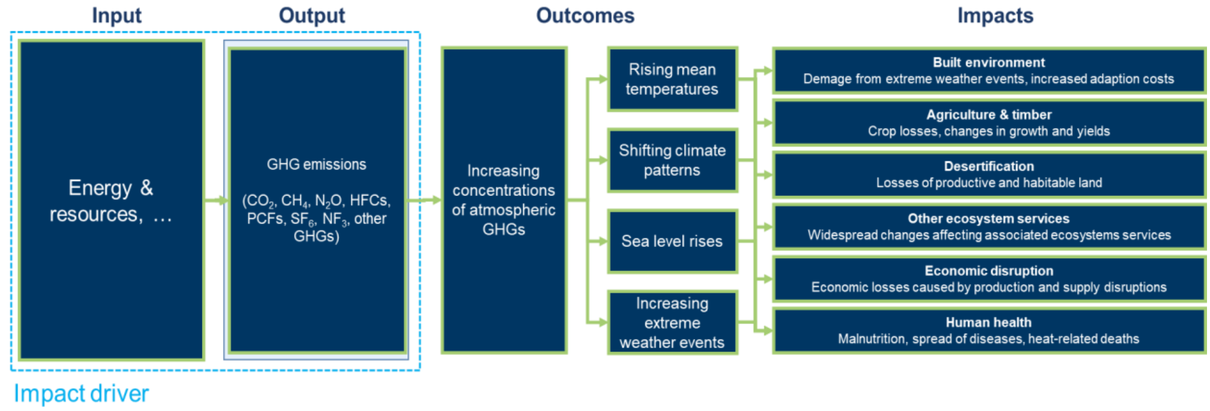

Figure 6: Impact pathway of GHG Emissions (source: own illustration)

Valuation approach

For the valuation of GHG emissions, we apply the widely used concept of social costs of carbon (SCC) (Nordhaus 2014). The SCC measures the damage caused by emitting an additional ton of GHG into the atmosphere, taking into account the impacts across all future years. The SCC is calculated based on an assumed future emission trajectory and is derived via so called integrated assessment models which combine economic modelling with climate models. These models factor in geophysical assumptions, such as climate sensitivity to atmospheric GHG stock concentrations, as well as economic variables like projected energy demand and available abatement technologies. Since GHG emissions contribute globally to climate change regardless of their origin, no country-specific valuation factors are required; GHGs accumulate in the atmosphere as a collective stock, making their location of release irrelevant for local impact (Stern 2008). Consequently, the value factor is equal across all countries and industries.

We use the well know DICE model developed by (Barrage and Nordhaus 2024). The DICE model maximizes welfare, subject to constraints on, among others, the carbon cycle, radiative forcing, temperature limits, production, and damage functions. The model generates an optimal time path for consumption, emissions, and climate change.

A key outcome of the model is the SCC, defined as the economic cost caused by emitting an additional ton of carbon to the atmosphere. The SCC can be used to inform policymakers about the optimal carbon price or carbon tax for climate policy. The SCC estimates vary across models, damage functions and discount rates.

Assumptions

The specification of the damage function and the economic impacts it includes remains a controverse topic. Barrage and Nordhaus (2024) construct the damage function using three components. First, they integrate the impact estimates from a literature synthesis, which suggest a GDP-equivalent loss of 1.6% at 3°C warming. The estimates consider impacts on sectors such as agriculture, health, and ecosystems (see Table 4 for an overview of climate impacts). However, the damages considered in the literature are not comprehensive and omit potential impacts such as ocean acidification, social unrest, and large-scale catastrophic events.

Second, an additional adjustment for tipping points is included, adding a further 1% output loss at 3°C warming. Finally, a judgmental adjustment adds a 0.5% loss at 3°C warming to account for uncertainties and unquantified factors.

Damage	Biophysical effect / Valuation	Impacts
Coastal zones (sea level rise)	Loss of land and damage to capital	Built environment
Extreme events	Capital damages from hurricanes, flood-related economic and mortality losses and mortality from the greater frequency and intensity of storms	Built environment
Commercial forestry	Change in forestry consumer and producer surplus	Agriculture and timber
Fisheries	Changes in fisheries catches	Agriculture and timber
Agriculture	Changes in crop yields, pasture- and rangeland	Agriculture and timber
Undernourishment	Morbidity and mortality caused by being underweight as a child	Human health
Health	Labor productivity (morbidity, occupational heat stress), mortality and morbidity from selected diseases, heat- and cold-related mortality, health expenditure, mortality from air pollution	Human health
Tourism	Changes in tourism flows or currency flows, quality of tourism services,	Economic disruptions
Energy demand	Changes in energy demand for cooling and heating, fuel switches	Built environment
Ecosystems	Loss of ecosystems, biodiversity, and landscapes	Other ecosystem services

Water resources / stress	Changes in water supply and demand	Built environment
Energy supply	Hydroelectric power generation capacity, thermal power generation capacity, cooling water shortages	Economic disruption Economic disruption
Economic consequences	GDP per capita / GRP per capita (growth), regional disparities, trade	Economic disruption

Table 4: Climate impacts included in the surveyed studies (source: own illustration)

When using the SCC as the valuation method, it is crucial to be specific about the valuation of future generations. The generational discount rate, also referred to as the pure rate of social time preference, reflects this value. A zero-discount rate implies equal valuation across generations, whereas a positive rate assigns less weight to future welfare compared to the present one.

In the DICE model the Ramsey equation links the pure discount rate with the social discount rate. It is expressed as:

$$R_T = \rho + \phi g_T,$$

where R_T is the social discount rate from time 0 to T, ρ denotes a pure rate of social time preference, g_T represents the growth rate of per capita consumption, and ϕ is the elasticity of the marginal utility of consumption, reflecting society's valuation of an additional unit of consumption and its degree of inequality aversion.

Barrage and Nordhaus (2024) consider scenarios with discount rates ranging from 1% to 5%. Lower discount rates (such as 1% or 2%) lead to much higher SCC estimates. Conversely, higher discount rates (such as 5%) result in lower SCC estimates. We recommend using the SCC estimates from the scenario where the discount rate is set at 2%. In this scenario, the elasticity of marginal utility of consumption is assumed to be 1, and the average growth of per capita consumption from 2020 to 2400 is approximately 1.5%. In addition, Barrage and Nordhaus (2024) examine six other scenarios. The **Baseline scenario** is the business-as-usual case, assuming current climate policies remain unchanged. The **Cost-Benefit Optimal scenario** maximizes welfare by balancing the present value of abatement costs with the benefits of reducing climate damage, assuming full global participation beginning in 2025. This approach follows cost-benefit analysis without additional constraints, such as specific temperature limits, and can serve as an efficiency benchmark for evaluating the other scenarios.

The **Temperature-Limited scenarios** are cost-benefit scenarios with an additional constraint on global temperature increase, targeting maximum warming of 2°C or 1.5°C above pre-industrial levels. The **Alternative Damage Function scenario** uses a damage function with a temperature-damage coefficient three times higher than that in the standard DICE model. Finally, the **Paris Accord Extended scenario** assumes that countries meet their 2030 climate commitments as pledged in summer 2022, implemented through an internationally harmonized carbon price.

4.1.4 Invasive Alien Species

Overview

Invasive alien species (IAS) are plants, animals, and microorganisms introduced, either intentionally or unintentionally, into regions where they are not native. Once established, these species often disrupt local ecosystems, competing with, preying on, or otherwise harming native species. Human activities such as global trade, tourism, and transportation have accelerated the spread of IAS, creating a growing challenge to biodiversity worldwide (Roy et al. 2023). According to the International Union for Conservation of Nature (IUCN), IAS are one of the top 5 drivers of biodiversity loss and the second most common cause of species extinctions. Overall, IAS risk is undermining progress towards achieving 10 of the 17 UN Sustainable Development Goals (SDGs) (IUCN 2018).

Quantifying the economic impact of IAS is challenging due to the diverse pathways through which these species affect ecosystems and the limited availability of comprehensive global data. Among the taxonomic groups, plants have the most extensive and consistent data on global distributions, ecological effects, and economic costs, making it feasible to focus on them for impact valuation. Consequently, this indicator specifically monetizes the impacts of *invasive alien plants*, which represent a significant portion of IAS-related biodiversity loss (Seebens et al. 2015).

Impact Pathway

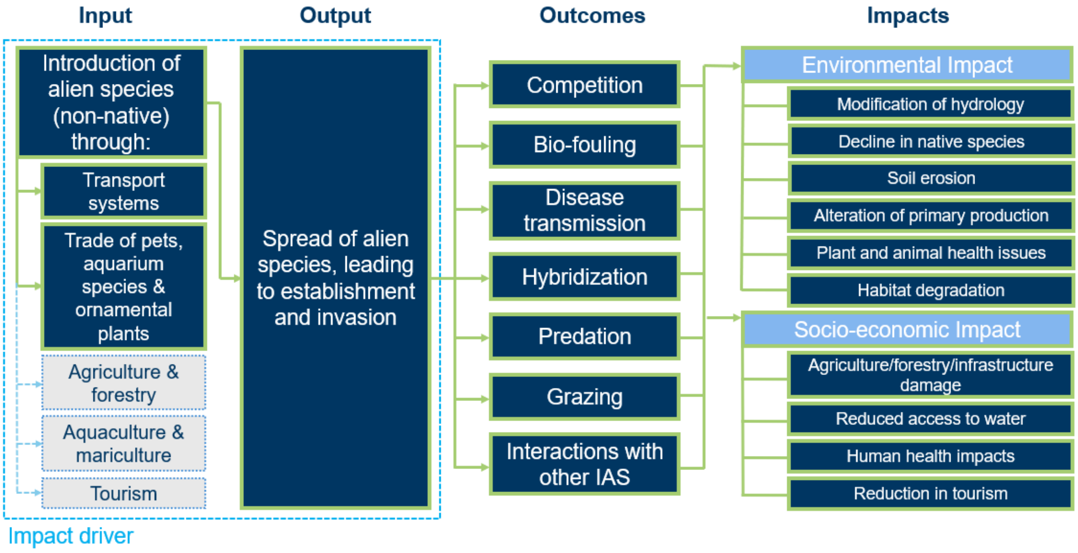

Figure 7: Simplified impact pathway of Invasive Alien Species (source: own illustration based on IUCN)

Alien species can be introduced into new environments through multiple pathways. Empirical studies show that global shipping for trade is the primary transport vector for invasive species (Deutz et al. 2020). However, other significant pathways include the pet trade, trade of ornamental species, agricultural and forestry activities, aquaculture, mariculture, and tourism. This indicator specifically focuses on the transport system as well as the trade of pets, aquarium species, and ornamental plants as central channels for IAS introduction.

Once established in new ecosystems, invasive species can disrupt native ecosystems in numerous ways, including competition with native species, bio-fouling, disease transmission, hybridization, predation, grazing, and interactions with other IAS. These disruptions lead to several environmental consequences, such as altering hydrology, reducing native species populations, accelerating soil erosion, disrupting primary production, causing health issues in plants and animals, and degrading habitats. The socio-economic impacts of IAS are equally substantial. They include damage to agriculture and forestry, increased costs for maintaining infrastructure, reduced access to clean water, negative effects on human health, and decreased tourism revenue due to the degraded natural landscapes and ecosystems.

Valuation approach

While the impact pathway maps the chain of effects from the spread of IAS on ecosystems and beyond, the actual impacts themselves are not directly monetized. 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 how IAS are linked to a decline in biodiversity.

Biodiversity conservation costs

An estimation of the global value of invasive alien species recently published in Financing Nature, was expressed as the total financial costs of managing IAS impacts globally. The authors estimate these costs between 36-84.3 billion $/year, incorporating a mix of investments in research, prevention measures to slow or stop further invasive species introductions, and control and eradication measures to address existing invasive species infestations (Deutz et al. 2020). We use the upper value to rather over- than underestimate impacts from IAS.

Global impact factor

To derive the global impact factor for invasive alien plants, the total annual costs attributed to invasive plant species were first estimated. This was done by calculating the share of costs specifically caused by invasive plants. According to IPBES, invasive plant species are estimated to number approximately 13,939, representing about 37.45% of the total invasive alien species globally (Seebens et al. 2023).

Research by Turpie and Jurk (2012) indicates that invasive plants account for 54% of the total economic impact from all invasive species. Using the upper estimate for total annual recurrent costs from invasive alien species, at $84.3 billion, the costs due to invasive plants alone are around $45.5 billion per year. Dividing these costs by the estimated number of invasive plant species yields a global impact factor of $326.6 million per invasive plant species per year.

$$global\ impact\ factor = \frac{total\ costs\ caused\ by\ plants}{total\ IAS\ plants}$$

Local adjustments

The sourced rates capture a global average. To adjust for local impacts, we assume that the number of threatened species by IAS per country, influenced by country size, correlates with the severity of biodiversity loss and associated costs. While it is likely that impacts are proportional to the number of species threatened by IAS in a country, some countries may be home to more threatened species simply due to larger country area. Therefore, we calculate a country-specific scaling factor based on each country's deviation from a predicted baseline that considers both threatened species counts and area. As done in Pyšek, P. et al.'s (2017) paper, a regression model using the log-transformed values of threatened species and country area establishes an expected number of threatened species for each country (Figure 8).

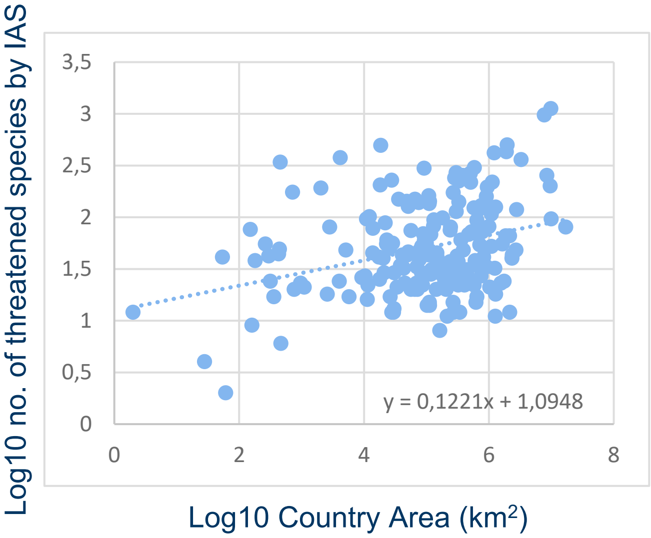

Figure 8: Logarithmic relationship between threatened species count and country area

The scaling factor is then calculated by dividing the actual by the predicted number of threatened species. This approach allows for a more accurate valuation of biodiversity loss, accounting for variations in species count relative to country size.

$$Local\ scaling\ factor\ of\ country_i = \frac{recorded\ threatened\ species\ count\ in\ country_i}{predicated\ threatened\ species\ count\ in\ country_i\ based\ on\ area}$$

Data on red-listed species per country is sourced 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. Thus, if a country has the same number of threatened species as one would expect, taking its area into account, then its activities are valued at the global impact value. However, if a country has a higher number of threatened species than expected for its area, then it is also more densely populated by threatened species, which leads to a higher than average impact factor.

$$Impact\ value\ in\ country_i\ and\ activity_j = local\ scaling\ factor\ of\ country_i * global\ impact\ value_j$$

Further research

In general, research on how to measure and value biodiversity (and invasive alien species as a part of it) 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.

4.1.5 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 (Woods et al. 2021). As of now, data to depict the effects of micro and nano plastic is missing (Wright and Kelly 2017).

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 originates from mismanaged waste (82% (OECD (2022)). 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-related costs across the plastic lifecycle are currently unquantifiable (WWF International and Dalberg 2021). These costs can emerge from production processes, waste management, usage, and unmanaged plastic waste. While studies indicate a connection between plastic and human health, the precise impact remains unclear (Wright and Kelly 2017). This is partly due to the dependency of health effects on plastic exposure levels, for which robust data are not yet available. Further research is necessary to clarify the health impacts of plastic waste and to support the monetization of these effects (Woods et al. 2021; Wright and Kelly 2017).

Impact Pathway

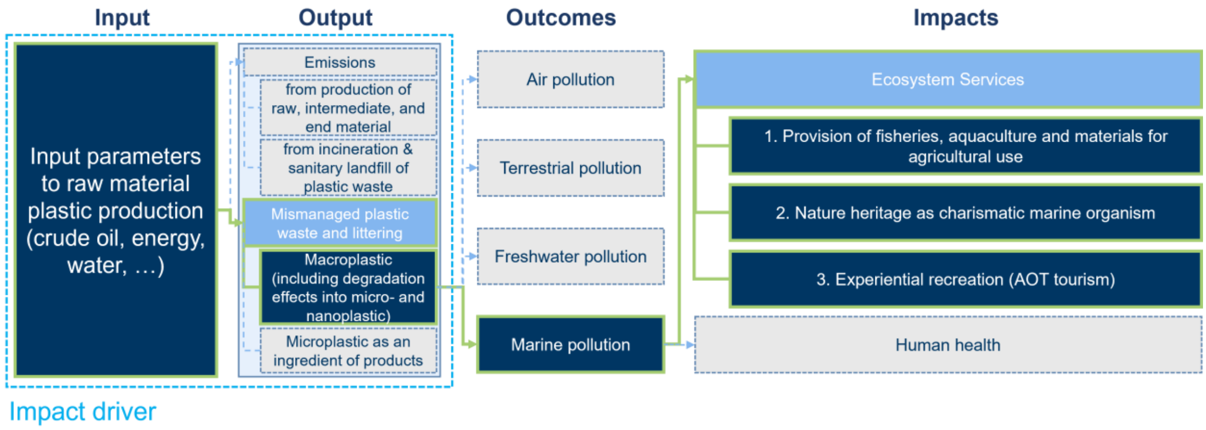

Figure 9: Simplified impact pathway of Marine Plastic Leakage (source: own illustration)

Valuation approach

To calculate the impact of leaked plastic to the aquatic environment, the transportation, fragmentation, and degradation of plastic has to be considered (Beaumont et al. 2019; WWF International and Dalberg 2021).

The annual amount of leaked plastic into the ocean is calculated and divided by the total global plastic production to determine an ocean leakage rate. Data on plastic leakage into aquatic environments is sourced from the OECD, and plastic production mass is aligned with PlasticsEurope figures. This global ocean leakage rate is applied uniformly across countries to estimate the quantity of plastic entering the ocean.

To value the damage from this leakage, we use the WWF's ecosystem services value estimate, which assigns a global value of $61.3 trillion per year to marine ecosystem services (Costanza et al. 2014). Beaumont et al. (2019) suggest that marine plastic reduces ecosystem services by 1-5%. This damage estimate accounts for economic losses from reduced fisheries, aquaculture, and agricultural materials; welfare losses from the degradation of natural heritage (such as the decline of species like sea turtles); and economic losses from reduced recreational services (e.g., polluted beaches). Using a conservative estimate of 1%, this implies a minimum cost of $4,085 per ton of plastic leaked into the ocean annually, according to WWF International and Dalberg (2021). Lifetime costs of ocean plastic leakage are calculated by applying a 1.5% social discount rate.

Finally, the estimated amount of leaked plastic is multiplied by the minimum cost per ton to derive the total damage costs for marine ecosystem service loss.

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.

4.1.6 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 (EPA 2022).

Impact Pathway

Various forms of human land use affect the environment and society in distinct ways. Any type of land use affects the ecological system (biodiversity). In addition, agricultural land use and mining activities impact the provision of clean drinking water, also affecting crop and wood growth capacity. Paving land for infrastructure, such as building roads and urban development, 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, leading to higher mortality rates, reduced working capacity and decreased 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.

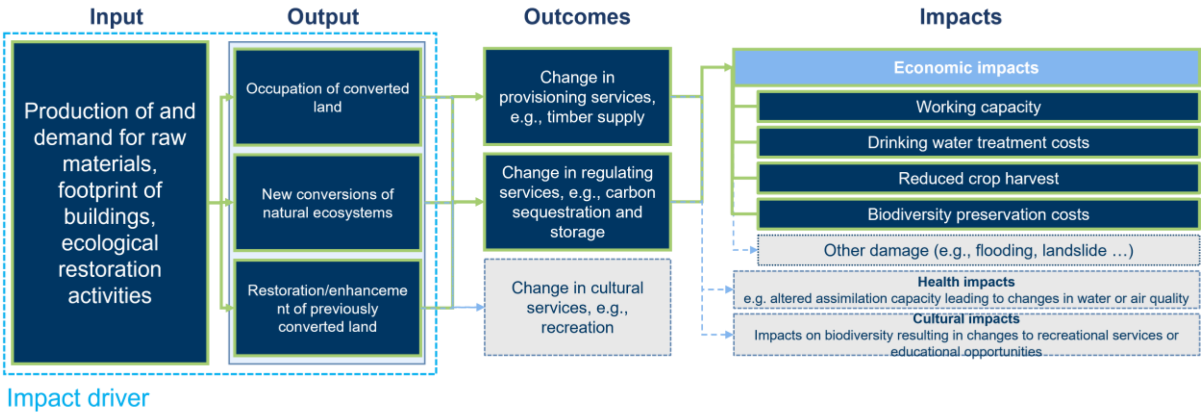

Figure 10: Impact pathway of Land Use (source: own illustration based on EPS (2015))

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 (Arendt et al. 2020; Steen 1999). The latest version was released 2015 and provides monetary values for various endpoint categories, including land use (Swedish Life Cycle Center 2015). The values depict impacts on biodiversity and agricultural damages. EPS land use categories and values were matched to WifOR categories as described in the first two columns of Table 5.

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 5: 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 (Swedish Life Cycle Center 2015; IVL Swedish Environmental Research Institute 2020) - adjusted from 2016 EUR/m² to 2020 USD/ha (third column of Table 5).

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.

Working capacity

With respect to the impact of urban land use on working capacity, we build on EPS (2015) using (Steen 2016). 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 between the age of 20-69 years (Steen 2016).
- We assume an employment rate of 0.65 (Steen 2016).
- 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 on 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 52 USD per hour (OECD n.d.), which gives 83,200 USD 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, equaling 0.286 in 2019 (World Bank 2019). Thus, the decline in working capacity globally was calculated as 0.00000715*83,200*0.286=0.17 USD/m^2.

Drinking water treatment costs

A second important driver of land use impact is the effect on drinking water. We obtain the elasticity water production costs with respect to the different types of land use surrounding the water source from Price and Heberling (2020). They measure the impacts of urban and agricultural land use on the variable water production costs, using forest land use as a baseline, and consider two types of water sources: surface water and groundwater. They find that urban land use significantly increases costs for surface water, 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. Since these effects apply either to surface water or groundwater, an estimation for the share of each source in the global water supply is needed. According to the UN Groundwater Report, each source contributes roughly a half of the global water supply (UNESCO 2022). 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 a limitation of these estimates is that they are based on U.S. data, no globally applicable data was available. The underlying assumption is that water purification technology and pricing are relatively uniform worldwide, with minimal variation across countries.

Biodiversity preservation costs

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 (Deutz et al. 2020). We use an estimate of the share of threatened species from the IUCN website (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 (Meijer et al. 2018).

Additionally, when mapping the EPS categories to the categories in the first column of Table 5, 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 impact of using 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 impact of land-use processes on ecosystem services (Bos et al. 2016; Fraunhofer IBP 2021). 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 value factors 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 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 (EEA 2014). 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.

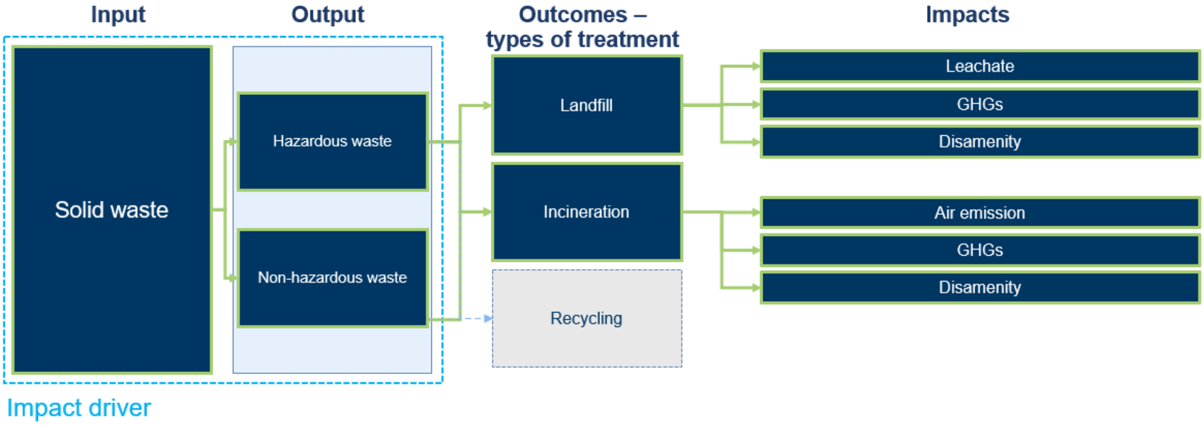

Figure 11: Impact Pathway of Waste (source: own illustration)

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, while disamenity is reflected by hedonic pricing ("willingness-to-pay"), and leachate by clean-up-costs. Although a universal damage cost approach is generally preferred, exceptions are necessary. This is because (1) the highly individual nature of perceived disamenity preventing a generalized assessment and (2) the damages of leachate are unknown as its impact pathway is not yet sufficiently understood (Steen 2020).

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). Value factors that express health damages are provided by EXIOPOL Project (2009) for heavy pollutants and PwC (2015) 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 Project (2009) and US values from PwC (2015). This is done by following the assumption that, the denser an area, the graver the health effects will be. The underlying extrapolation metric is a country's population density in 2020 retrieved from the World Bank (2020b).

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), 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 6: CO2 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 value factors were retrieved:

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

Table 7: Value factors for CO2

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 50-55% of landfill gas and 45-50% of CO_2 (IPCC 2006). Small amounts of other gases include nitrogen dioxide (Rieradevall et al. 1997). 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. As methane makes up approximately half of landfill gas and in the absence of better data, the same amount of CO_2 is 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 (Interagency Working Group on Social Cost of Greenhouse Gases, United States Government 2021). The social cost of carbon is the same as stated in Section 0 (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 8: Value factors for CH4

In a last step, the value factors 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 value factors 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 (Cambridge Econometrics et al. 2003). 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 (2022b)) and (2) the household density (we retrieve data on household density from United Nations, Department of Economic and Social Affairs, Population Division (2017)). The assumption is that the higher the housing prices, the more severe the effect of 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 (Singh 2012), 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 9: 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 10: 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 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.

4.1.8 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 increase the risk of diseases, such as cholera, typhoid fever, and other water-borne illnesses (WWF 2022). Water stress further supports insufficient irrigation of crops that consequently leads to farming losses.

Impact Pathway

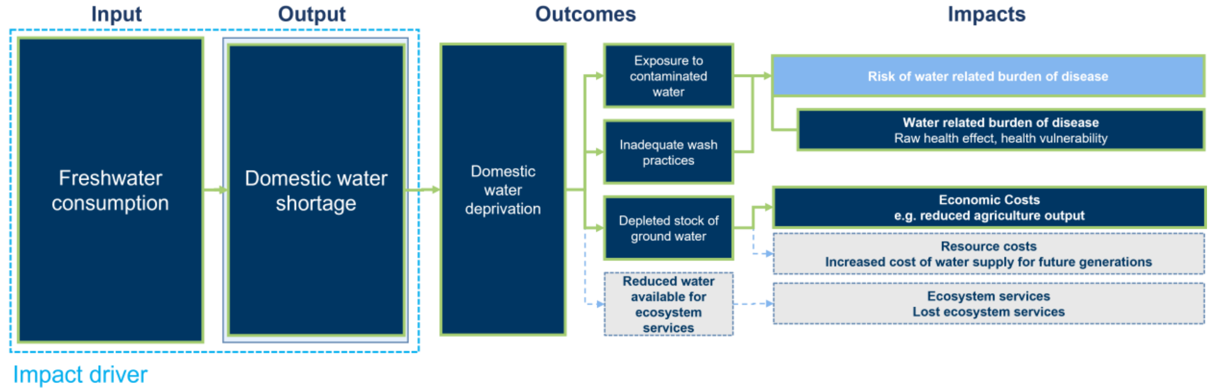

Figure 12: Impact Pathway of Water Consumption (source: own illustration)

Figure 12 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 effects 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 reflects economic damages and the second comprises damages to human health. These are then summed up to a total damage cost.

- **Economic damages:** The global water shadow price proposed by Ligthart and van Harmelen (2019) is used as a baseline. The value represents the loss of economic gains in agriculture due to inadequate freshwater supplies that result from 1 m^3 water usage. As local water scarcity determines the severeness of these damages, we use country specific water scarcity factors (according to the AWARE model (WULCA 2021b)) 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 (Debarre et al. 2022). 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 and van Harmelen (2019), which values a m³ of water at 5.17 €. 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 (Arendt et al. 2020). 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 available water remaining 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 (WULCA 2021a). 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:

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

B) Damages to Human Health

In contrast to the valuation of economic damages, local value factors 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/m^3. 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 value factor for water consumption expressed in USD per m³ water consumption is obtained.

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

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 value factors, the impact on ecosystem services or increasing costs for future generations are not valued. This approach is therefore rather conservative.

4.1.9 Water Pollution

Overview

Many economic activities cause 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 13 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 that these elements are already covered in other indicators.

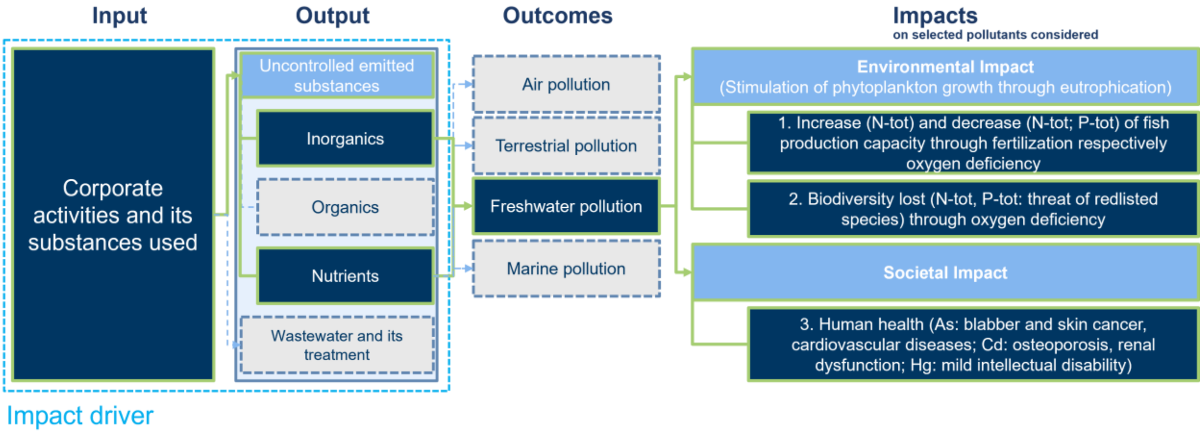

Figure 13: Simplified impact pathway of Water Pollution (source: own illustration based on Steen (2020)).

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. 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 2015a; 2015c; 2018).

We constructed the indicator via the following steps:

Step 1: Basis of the water pollution indicator are the depictions of global emissions to water in Steen (2020) in adjusted 2018 USD.

- Nitrogen N-tot to Freshwater 2.40E-03 $/kg N-tot (p.176)
  - N-tot donates total bounded Nitrogen, N_2 (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, Nickel, Copper, Zinc, and Antimony) based on Mercury. Data describes health-related impacts (USEtox 2015b).

Step 3: For the regional distribution of global data, we use water scarcity data per country from the World Bank (2023).

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 (USEtox 2015a; 2015c; 2018). Therefore, we give a weight on each country according to the water scarcity indicator provided by the World Bank (2023). 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 by 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 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.

4.2 Human rights and social indicators

4.2.1 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” (ILO 2019). 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 (ILO and UNICEF 2021).

Although the children working may experience some benefits (e.g., better nutrition, greater control over resources being spent in their favor) (Edmonds 2016), there are a variety of negative impacts for children and society that overall exceed potential benefits (Gordon 2008). 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. This harm can have not only short- but potentially also long-term implications on health. The impacts are, however, difficult to quantify due to lack of data (S. Vionnet, Friot, et al. 2021e; Pereznieto et al. 2014).

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 adult work life is estimated, a common in the literature (World Vision 2016). The result is a country-specific economic damage cost estimate for a case of child labor.

Impact Pathway

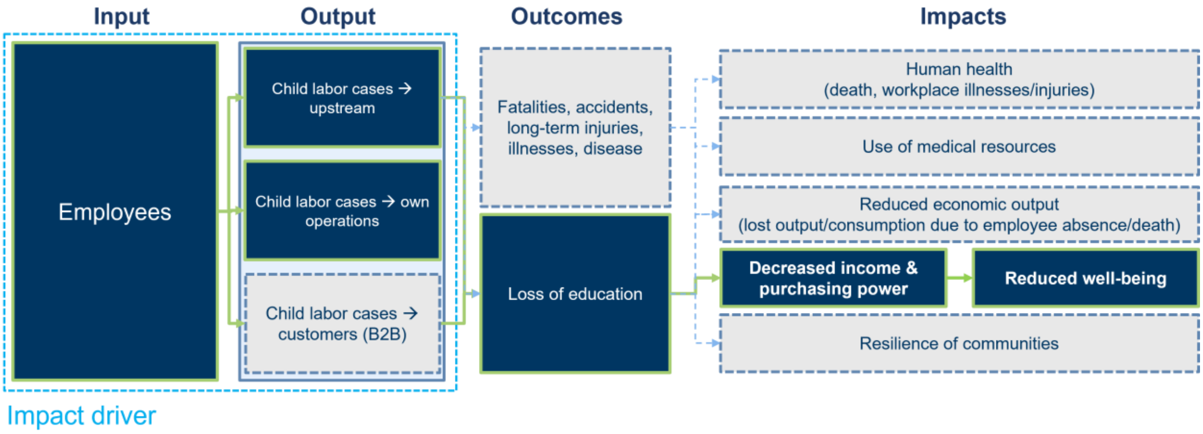

Figure 14: Simplified impact pathway of Child Labor (source: own illustration)

Valuation approach

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

The latest data on income returns for an additional year of schooling is provided by Psacharopoulos and Patrinos (2018). We use the overall returns to schooling, estimated by the Mincerian rate of return. Returns to education over all grades are chosen as we are interested in returns to education across all age groups. Estimates are available 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 calculated by multiplying the return to schooling (in percentages terms) by 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 (World Bank 2021a) to reflect both the impact on individual income and the potential productivity losses to society.

B) *Adult working life*

To estimate lifetime income and productivity losses, the adult working life in the country is considered, calculated as the difference between age 18 and the official retirement age. Where the official retirement age is less than 5 years above life expectancy of a current 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 discount rate of 1.5%.

Life expectancy at birth - the number of years a newborn infant would live if current mortality patterns remained constant - is taken from the WDI Indicators Database (World Bank 2021b).

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

- OECD (2019), 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 (2021), collecting the statutory pensionable age,
- The Social Pensions Database by Pension Watch (2018), 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 "more 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." (ILO and UNICEF 2021). 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.

4.2.1 Disability Discrimination

Overview

Within the framework of the German Supply Chain Due Diligence Act (LkSG), the violation of equal treatment regarding, among others, people with disabilities, is mentioned as a human rights risk according to §2 paragraph 2 No. 7.

Therefore, the indicator Disability Pag Gap was developed to capture the potential risks of discrimination against people with disabilities along the supply chain.

The approach starts by identifying the number of people that are potentially at risk, i.e. people with disabilities who participate in the labor market in a country. Next, it focuses on the wage difference between employees with and without disabilities. The monetization pathway follows the idea that these wage differences can be related to a negative health impact (S. Vionnet, Schaumberg, et al. 2021a; 2021b).

Impact Pathway

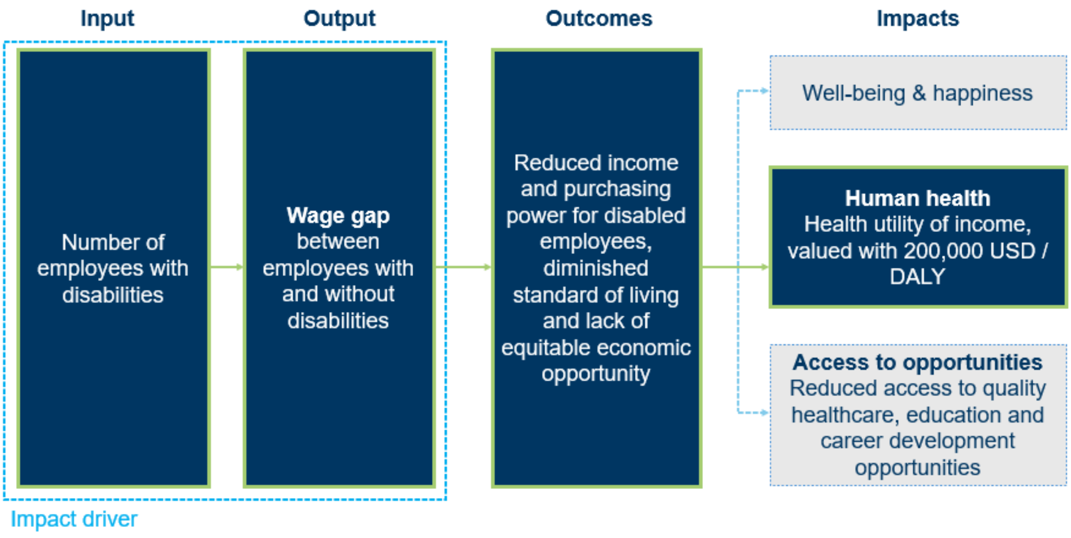

Figure 15: Impact pathway of Disability Discrimination (source: own illustration)

Valuation Approach

The monetization approach aims to express the negative impact related to violations of equal treatment for disabilities in a monetary value. For this purpose, the estimated disability pay gap (physical indicator) is interpreted as lost income due to discrimination. Further, the lost income is translated into DALYs by multiplying it with the Health Utility Index (HUI) factors that capture the relationship between health and income. This is followed by a multiplication with the value of statistical life (VSL), which is intended to capture the economic value of one year of a human life lived in a good condition of health and corresponds to USD 200,000 per year. At this stage, the impact per affected person is calculated. To capture the complete impact in monetary terms, the impact per affected person is multiplied with the physical indicator, which is the number of employees with a disability. The calculation is depicted in the following formula:

$$\begin{aligned} & Gender\ gap\ gap\ impact_{c,s} \\ & \qquad = Employees\ with\ a\ disability_{s,c} \times disability\ pay\ gap\ per\ affected\ person_{c,s} \\ & \qquad \times\ HUI_c\ \times VSL \end{aligned}$$

with c = country and s = sector.

Assumptions

Each US Dollar of the disability pay gap is valued equally regarding the health impact and regardless of the average income level per country-sector combination.

Future research

Further research work could consider a decreasing marginal utility of income and estimate the impact based on country-sector specific income levels.

4.2.2 Fair Wages

Overview

The fair wages indicator challenges the assumption that every job has a positive impact on society. It assesses the quality of employment by valuing the impact of the wages paid to employees on their quality of life. 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 (Vionnet and Haut 2018; Vionnet et al. 2021).

A wage threshold is introduced against which wages are evaluated. This '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 reduces 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 how many disability-adjusted life years (DALYs) are gained per USD of income by country. 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, additional income allows 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 further 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.

Impact Pathway

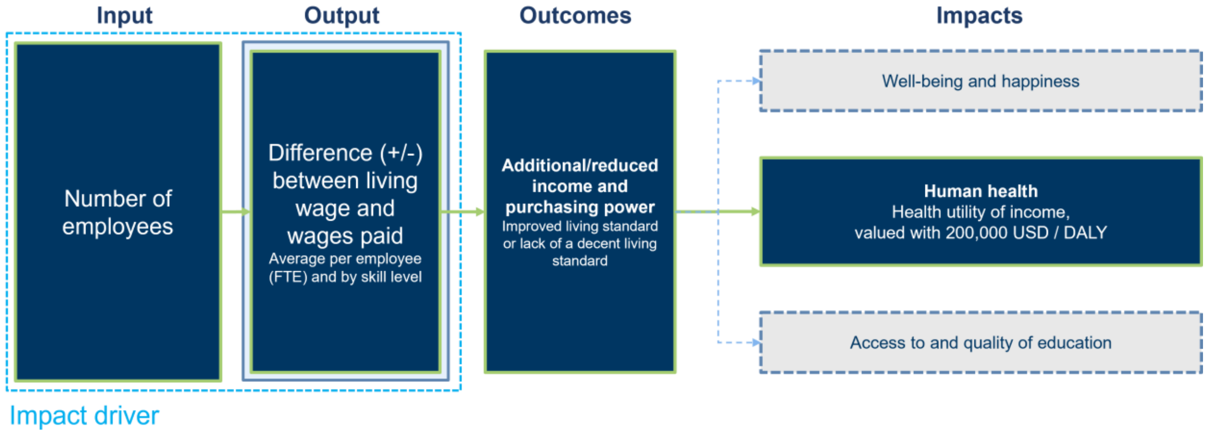

Figure 16: Simplified impact pathway Fair Wages (source: own illustration)

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, regardless whether it is below or above the baseline. However, a **cutoff point** is set at an income of **four times the living wage** in each country. Above this threshold, no additional income is valued. This approach assumes that for people with an income at or above four times the living wage, any additional income has no effect on their wellbeing.

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 adopt assumptions based on the originally suggested approach for marginal HUI factors as outlined by Vionnet and Haut (2018), shown in Table 11.

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 11: HUI values following Vionnet and 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 11 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.

Another crucial assumption is that an income equal to the country-specific living wage has an impact of zero. Any additional income has a positive effect, any deficit a negative impact.

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 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 (2020). 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. (2021). 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.

4.2.3 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 (ILO and Walk Free Foundation 2017).

Forced labor has different effects on the life quality of victims. On the one hand, they are exposed to a higher risk of injury or fatality than normal. However, these impacts lack data input (Vionnet et al. 2021). 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 per forced labor victim in USD.

Impact Pathway

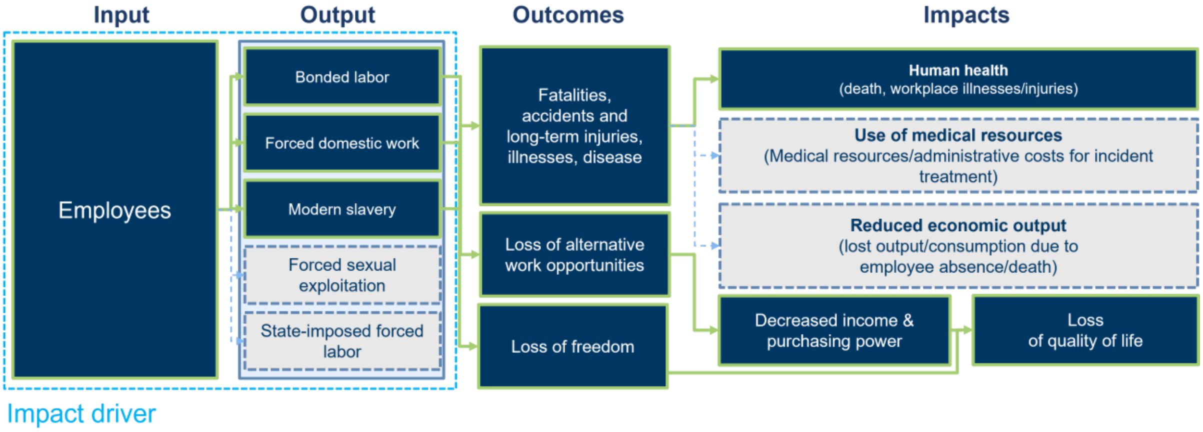

Figure 17: Impact pathway of Forced labor (source: own illustration)

Assumptions

We do not account for the costs of medical resources due to a health impairment, nor do we consider the reduced economic output due to the physical and mental limitations. Our focus is solely 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. (2016) 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 (2017) finds that more than 60% of their sample reported clinically significant depression symptoms, 46% clinically significant anxiety symptoms, and 47% expressed 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 (2020) 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 of forced labor on the quality of life. 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, 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 Labour Organization (ILO) 2014) has estimated profits made through forced labor for non-domestic and domestic forced labor.

B1) Non-domestic forced labor

ILO (2014) provides estimates for annual profits per victim in non-domestic private forced labor. 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.

$$\begin{aligned}&withheld\ income\ of\ a\ forced\ labor\ victim\\&= withheld\ income\ share\ * average\ sectoral\ labor\ compensation\ per\ employee\end{aligned}$$

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 shows that, on average, domestic workers in forced labor are deprived of 60 per cent of their due wages” (ILO 2014) 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.

4.2.1 Freedom of Association

Overview

Within the framework of the German Supply Chain Due Diligence Act (LkSG), the failure to respect freedom of association and the right to collective bargaining (No. 6) is mentioned as a human rights risk according to §2 paragraph 2 No.6.

Therefore, the indicator Freedom of Association was developed to capture the potential risk of violation along the supply chain.

The approach starts by focusing on countries where the risk for this kind of violation is rather high. Based on this, the amount of people that could be potentially affected is assessed. The monetization pathway follows the idea, that these affected people might experience disadvantages regarding their income level. Further, a lower income is associated with potential negative health outcomes (Vionnet 2021a; 2021b).

Impact Pathway

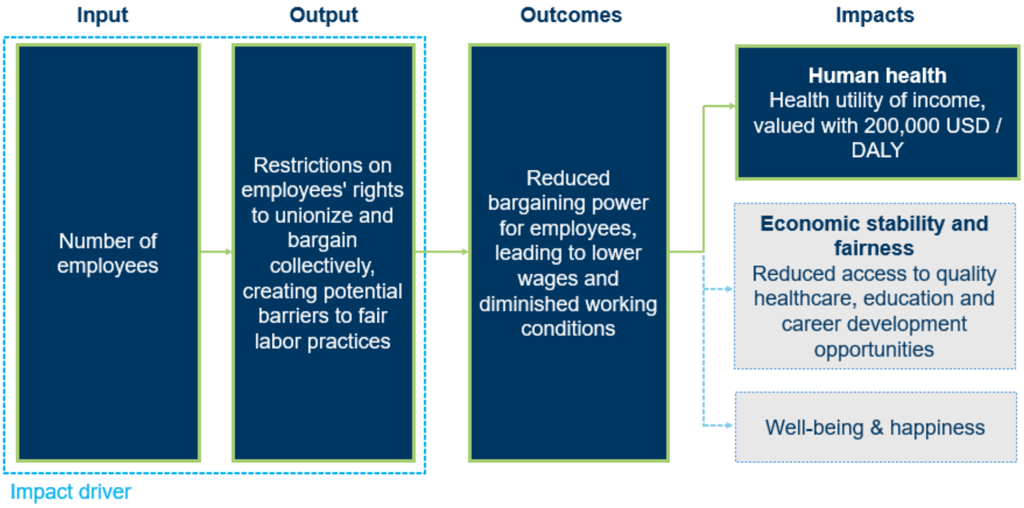

Figure 18: Impact pathway of Freedom of Association (source: own illustration)

Valuation Approach

The monetization approach aims to express the negative impact associated with violations of freedom of association and the right to collective bargaining in a monetary value. The valuation is based on the literature from the ILO Social Dialogue Report (2022) & Farber et al. (2018), who examined the relationship between union membership and the level of family income in the USA. Their study states that the family income of a union household is on average 10-20% higher than the income of a non-union household. This income disadvantage is interpreted as lost income due to the lack of collective bargaining and therefore restricted freedom of association. To avoid overestimating the effect, 10% is used to calculate the income loss. Hence, the share of 10% is combined with average compensation data (Wood et al. 2015) per person as a first step, which is interpreted as lost income per person. Next, the lost income is translated into DALYs by multiplying it with the Health Utility Index (HUI) factors that capture the relationship between health and income. This is followed by a multiplication with the value of statistical life (VSL), which is supposed to capture the economic value of one year of a human life lived in a good condition of health and corresponds to USD 200,000 per year. Until now, the impact per affected person is calculated. To capture the complete impact in monetary term, the impact per affected person is multiplied with the physical indicator, i.e., the number of affected employees. The calculation is depicted in the following formula:

$$\begin{aligned} &Freedom\ of\ association\ impact_{c,s} \\ &\qquad = Affected\ employees_{s,c} \times\ 0.1 \times average\ employee\ compensation_{c,s} \\ &\qquad \times\ HUI_c\ \times VSL \end{aligned}$$

with c = country and s = sector.

Assumptions

Due to the lack of sectoral and country differentiation in the data and reviewed literature, the value of 10% in income difference is assumed over all countries and economic sectors. Additionally, each US Dollar of lost income is valued equally regarding the health impact and regardless of the average income level per country-sector combination.

Future research

The approach does not cover a country- and sector-specific valuation. Further research could determine country- and sector-specific income losses that are associated with a lack of freedom of association. Additionally, further research could also consider a decreasing marginal utility of income and therefore estimate the impact based on country- and sector-specific income levels. This could contribute to an improved representation of actual working conditions.

4.2.2 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 (Hassanzadeh et al. 2014; Pinho-Gomes et al. 2022). The resulting health impact is estimated in Disability Adjusted Life Years (DALYs).

Impact Pathway

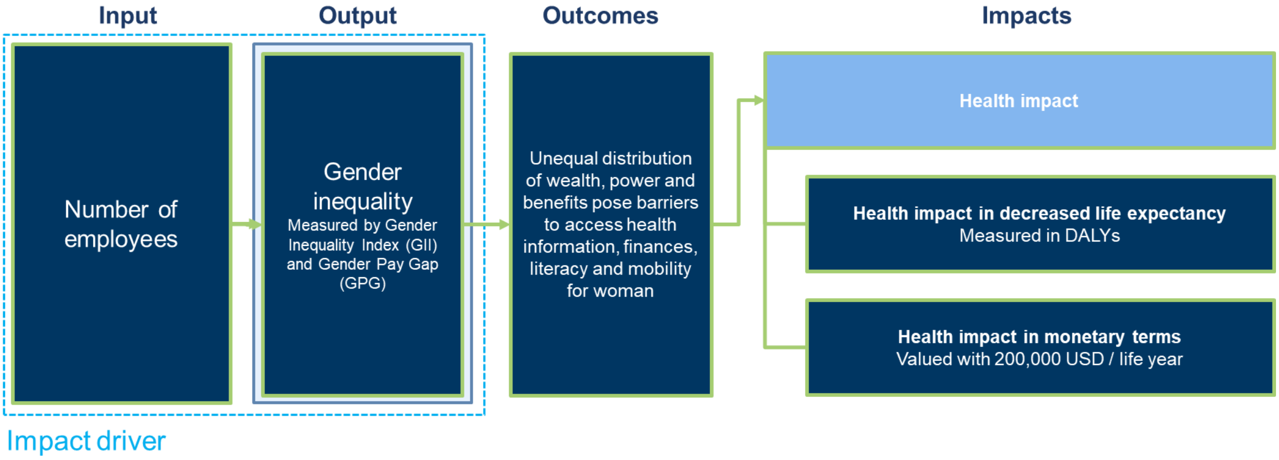

Figure 19: Impact pathway Gender Pay Gap (source: own illustration)

Valuation approach

Gender inequality is commonly expressed using the gender inequality index (GII). Vaes et al. (2021) analyzed 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 20). 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 20). By bringing the above together it can be concluded that a 10% GPG, correlates with a 0.2 year 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 (see chapter 3.3).

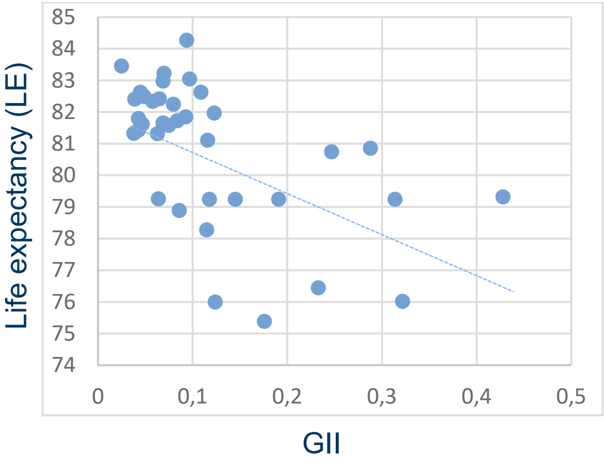

Figure 20: Correlation of GII and LE following Vaes et al. (2021)

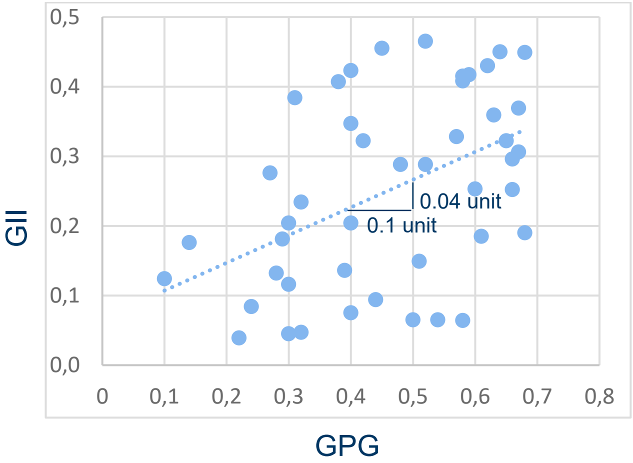

Figure 21: Correlation between GII and GPG done by WifOR

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 (International Labour Organization 2018) with the absolute number of employees split by male and female per economic activity from Exiobase 3 (Stadler et al. 2018).

B) Gender Inequality Index (GII)

The United Nation’s indicator for measuring gender inequality, the GII (United Nations Development Programme 2020) depicts three dimensions as measurements for inequality among men and women: reproductive health, empowerment, and the labor 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 (Eurostat 2022).
- The average life expectancy used is 72.7 years, which is the average life expectancy at the global level (World Bank 2020b).
- 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.

4.2.3 Land Eviction

Overview

Within the framework of the German Supply Chain Due Diligence Act (LkSG), the unlawful violation of land rights is mentioned as a human rights risk according to §2 paragraph 2 No.10.

Therefore, the indicator Land Eviction was developed to capture the potential risk these violations along the supply chain.

Land eviction deals are particularly found within the agricultural sector. The approach aims to identify affected workers within the agricultural sector that lose their work opportunities and consequently their income due to illegal land eviction deals. It is assumed that the loss of work opportunities is irreversible, and workers lose their lifetime income. Further, this lost income is associated with potential negative health outcomes (Vionnet et al. 2021; 2021).

Impact Pathway

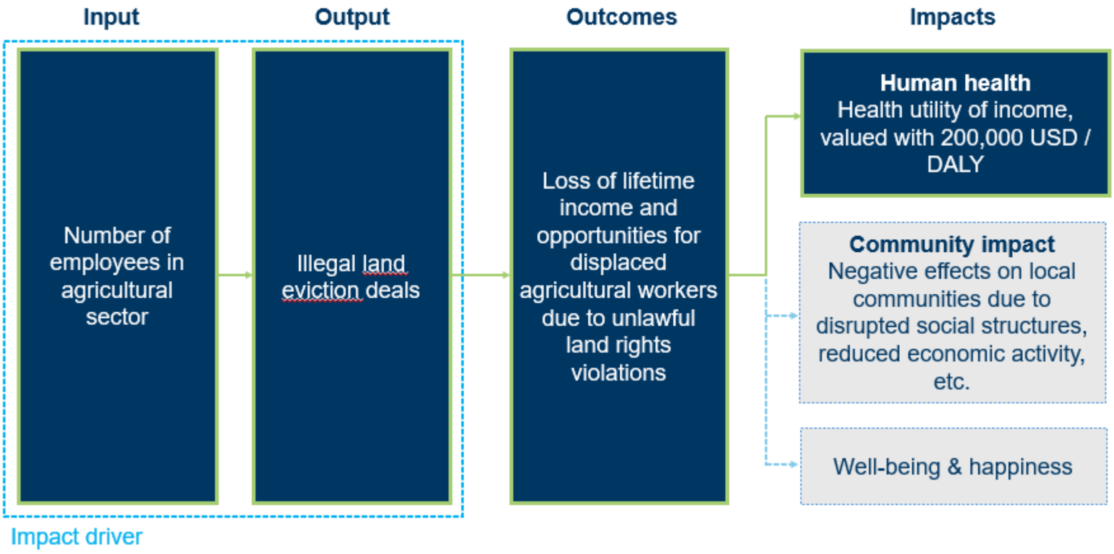

Figure 22: Impact pathway of Land Eviction (source: own illustration)

Valuation Approach

The monetization approach aims to express the negative impact related to unlawful land eviction deals in a monetary value. This approach is mainly based on the FAO Dataset on Family Farming (smallholders). It contains information about household income and household size per country. Based on this data, the income per person is calculated. For missing countries, regional averages are calculated and applied. It is assumed that this income will be the lost due to land eviction deals. Furthermore, it is assumed that the lost work opportunity is irreversible and therefore the income will be lost for a lifetime. For that, the perpetuity is calculated with an interest rate of 1.5%.

Next, the number of affected people is multiplied with the lost lifetime income per person, translated into DALYs by multiplying with Health Utility Index (HUI) factors, and valued by the Value of Statistical Life (VSL) which corresponds to USD 200,000 per year. The valuation can be depicted as the following formula:

$$Land\ eviction\ impact_{c,s} = Affected\ people_{c,s} \times lifetime\ income\ per\ person_{c,s} \times HUI_c \times VSL$$

with $lifetime\ income\ per\ person_{c,s} = \frac{Annual\ income\ per\ person_{c,s}}{interest\ rate}$ and c = country, s = sector.

Assumptions

It is assumed that being affected by an unlawful land eviction deal leads not only to lost income within the year but also to lost income over one's lifetime, since the lost work opportunity is irreversible.

Future research

The dataset does not contain income data for all relevant countries. Further research could identify ways to improve country coverage. This could contribute to an improved representation of the socioeconomic risk associated with land eviction.

4.2.4 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 costs caused by occupational injuries and illnesses, for example production losses, long-run losses of human capital, health-care related costs, administrative costs, or negative impacts on human well-being, and loss of life quality. The distribution of the overall cost across these stakeholders differs by country, influenced by factors such as the structure of the social security system (Safe Work Australia 2015; European Agency for Safety and Health at Work 2019).

Impact Pathway

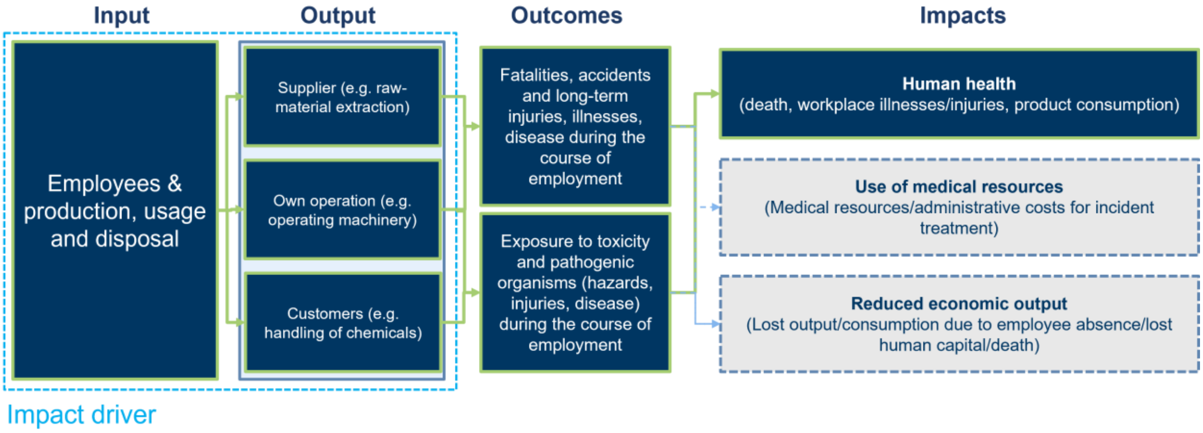

Figure 23: Simplified impact pathway of Occupational Injuries and Illnesses (source: own illustration)

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

Valuation Approach

This valuation focuses on the impacts on wellbeing of affected employees due to health impairments. 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 (International Labour Organization 2019) and their life expectancy (World Bank 2021b). 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 (refer to 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 an occupational incident, is defined as the difference between the age of death and life expectancy. This absolute number of years is then age weighted. A year of 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.

Based on the age-weighting and discount formula commonly used in the literature, e.g., by the World Health Organization (Murray 1994; Prüss-Üstün et al. 2003), the following equations yield the DALYs per country:

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

Due to the age-weighting and discounting influenced by the demographic characteristics of each country, the value factors 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. This are derived using Eurostat data on diagnoses (Eurostat 2022a; 2022b) of occupational illnesses and injuries within the European Union. The diagnoses are matched with an average severity disability weight from the Global Burden of Disease 2013 study (Salomon et al. 2015). For the duration of impairment, we calculate the average length of absence weighted by number of cases (Eurostat 2022c; 2022d).

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 workforce.

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

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

4.2.1 Rule of Law

Overview

Within the framework of the German Supply Chain Due Diligence Act (LkSG), the violation of the prohibition on the commissioning or use of private/public security forces that can lead to impairments due to a lack of instruction or control is mentioned as human rights risk according to §2 paragraph 2 No. 11. Further, the violation of the prohibition of an [...] act or omission in breach of duty which is directly capable of impairing a protected legal position (= further human rights) in a particularly serious manner, and the unlawfulness of which is obvious upon a reasonable appraisal of all the circumstances in question is mentioned as human rights risk according to §2 paragraph 2 No. 12.

Therefore, the Rule of Law indicator was developed to capture the potential risks of human rights abuses by security forces and further human rights violations along the supply chain.

The approach starts by focusing on countries where the risk of such violations is rather high, in order to first capture the amount of people that could potentially be affected. The monetization pathway follows the idea, that these affected people might experience a negative impact on their quality of life, health and life expectancy.

Impact Pathway

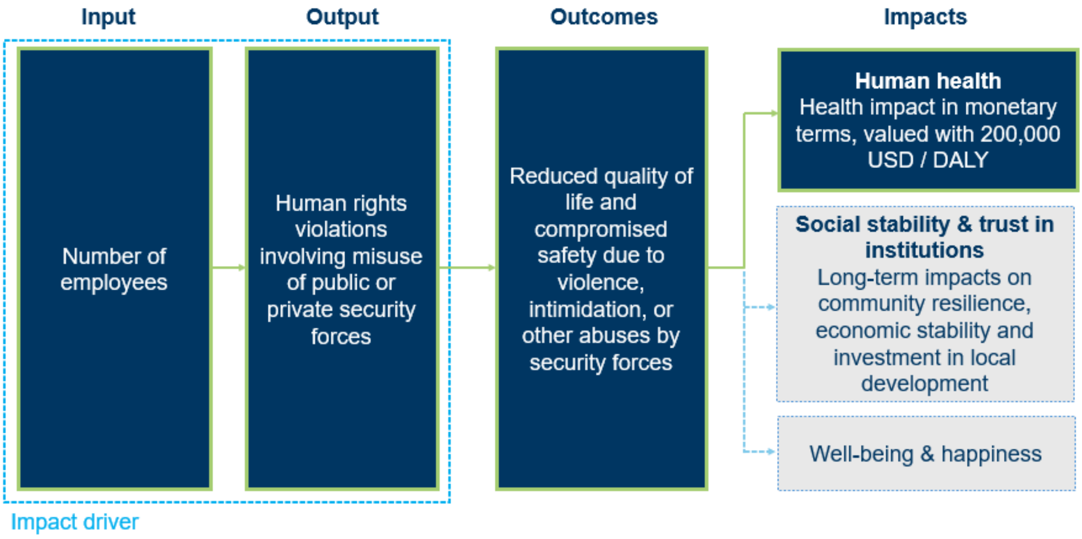

Figure 24: Impact pathway of Rule of Law (source: own illustration)

Valuation Approach

The monetization approach aims to express the negative impact related to violations of the rule of law in a monetary value. The valuation is based on a study by Pinzon-Rondon et al. (2015), who examined the relationship between the rule of law and health outcomes, measured among others in terms of life expectancy. The study indicates that for each 0.1 increase in the index value, life expectancy increases on average by 4.93 years. This information combined with the graphical illustration of the analyzed relationship by Pinzon-Rondon et al. (2015), allows to assign each country a life expectancy value based on its index value for rule of law, as depicted in the following table:

	Rule of law index value	Life expectancy	Source
min	0.1	47.35	Estimated with mean and coefficient
	0.2	52.28	Estimated with mean and coefficient
	0.3	57.21	Estimated with mean and coefficient
	0.4	62.14	Estimated with mean and coefficient
	0.5	67.07	Estimated with mean and coefficient
	0.6	**72**	**Read from graph in Pinzon-Rondon et al. (2015)**
	0.7	76.93	Estimated with mean and coefficient
	0.8	81.86	Estimated with mean and coefficient
	0.9	86.79	Estimated with mean and coefficient

max	1	91.72	Estimated with mean and coefficient

Table 12: Estimated Life Expectancy Based on Rule of Law Index

For the monetization we include all countries, not just the ones with higher risks, because no country reaches the maximum index value and therefore, contributes to the negative social impact. The reduction of life expectancy is then calculated on the country level by taking the difference between the country-specific life expectancy value and the optimal life expectancy associated with the rule of law index value of one. Since the effect is intended to be calculated only for one year, the number is adjusted by dividing the reduced life expectancy by the country's life expectancy. This reduction is then interpreted as DALYs.

This value is then multiplied with the value of statistical life (VSL) which is supposed to capture the economic value of one year of a human life lived in a good condition of health, which corresponds to USD 200,000 per year. At this point, the impact per affected person is calculated. To determine the complete impact in monetary terms, the impact per person is multiplied with the number of employees. Due to the granularity of the source, the peculiarity here is that not only the affected employees (physical indicator), who work in countries with a higher risk, are considered, but all employees working in countries with non-optimal circumstances are included for the monetized impact. The whole calculation is depicted in the following formula:

$$Rule\ of\ Law\ impact_{c,s} = Employees_{c,s} \times\ DALYs\ per\ person_{c,s} \times VSL$$

with c = country and s = sector.

Assumptions

Due to the lack of sectoral differentiation in the data and reviewed literature, the level of rule of law violations is assumed to be equal across economic sectors.

Future research

This approach does not cover a sector-specific valuation. Further research could identify sector-specific violations regarding the rule of law. This could contribute to a more accurate representation of actual working conditions.

4.2.2 Training

Overview

The total societal value created by corporate training is the accumulated increase in economic productivity of each individual trained, lasting until their retirement, based on 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 in income per year of schooling. These are scaled to the rate of return for one *hour* of schooling. This hour-rate is then multiplied with country- and sector-specific labor productivity, estimated by GDP per capita. Assuming that these productivity gains 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 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.

This approach follows a capital perspective on training, treating it as an investment in human capital. By training its employees, a company increases its human capital stock, which remains productive in the following years, regardless of whether employees stay or leave the company. It thus has the form of own work capitalized. This concept is similar to material capital stocks such as machinery or buildings constructed for the company's use. The net present value of future productivity of such material capital stocks is accounted for in balance sheets and discounted in future years as it is used up. The same logic can be applied to intangible capital, like human capital developed through training.

Impact Pathway

Figure 25 describes the impact pathway of training. We do not consider the outcomes which is associated with individual improvements like increase in self-confidence, as those properties are difficult to measure. Instead, we focus on increased knowledge and skills which result 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.

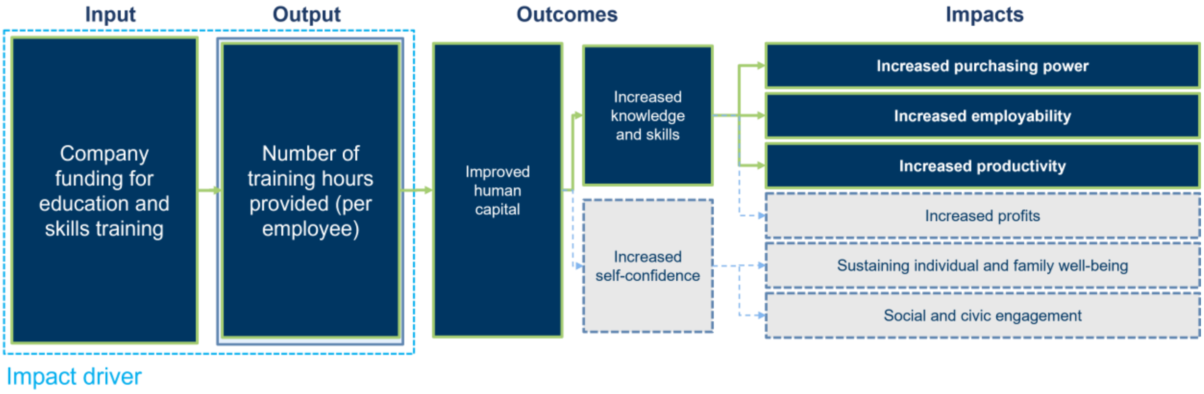

Figure 25: Simplified impact pathway of Training (source: own illustration)

Assumptions

The key assumption is that productivity returns from corporate training are comparable to returns-to-income from schooling. The assumption operates on two levels. First, it is assumed that the effects of an hour of training is similar to an house of schooling. 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*, which 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 may also vary depending 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 country specific, it is assumed constant across sectors. Yet, we use sector-specific productivity values, so while the relative increase in productivity per hour of training is constant across sectors, the absolute value depends on the baseline productivity level.

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

Valuation approach

A) Returns to schooling

The latest source on income returns to a year of schooling is provided by (Psacharopoulos and Patrinos 2018). There are two main methods to estimate the return to education: a) the Mincerian method, which provides overall private return estimates to education, and b) the full discounting method, which distinguished returns based on levels of education.

Where available, 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 (2019) provides data on the average hours per year of intended instruction time in lower secondary education. If unavailable, compulsory instruction time is taken. As a second source we use NationMaster (2000), 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 International Labour Organization (2019). 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 (2019), 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 (2021), collecting the statutory pensionable age,
- the 'Social Pensions Database' by Pension Watch (2018), 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 constant, is drawn from the World Bank (2021b). Where the official retirement age is less than 5 years above life expectancy of a person at the median age of the workforce, we deduct 5 years from the average life expectancy to approximate the end of working life.

Formula

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$\beta = discount\ rate$

4.2.3 Working Overtime

Overview

Within the framework of the German Supply Chain Due Diligence Act (LkSG), the disregard for occupational health and safety and work-related health hazards is identified as a human rights risk according to §2 paragraph 2 No.5. More specifically, the law addresses the lack of measures to prevent excessive physical and mental fatigue, particularly through inadequate work organization regarding working hours and rest breaks. The indicator Working Overtime was developed to capture this potential risk along the supply chain.

The International Labor Organization (ILO) defined a limit for hours worked per week regarding industrial and service sectors. According to ILO conventions, it was ratified that working hours should not exceed 48 hours per week on average (International Labour Organization 1919; 1930). It is categorized as an occupational risk factor that could lead to negative health outcomes (World Health Organization and International Labour Organization 2021a).

Impact Pathway

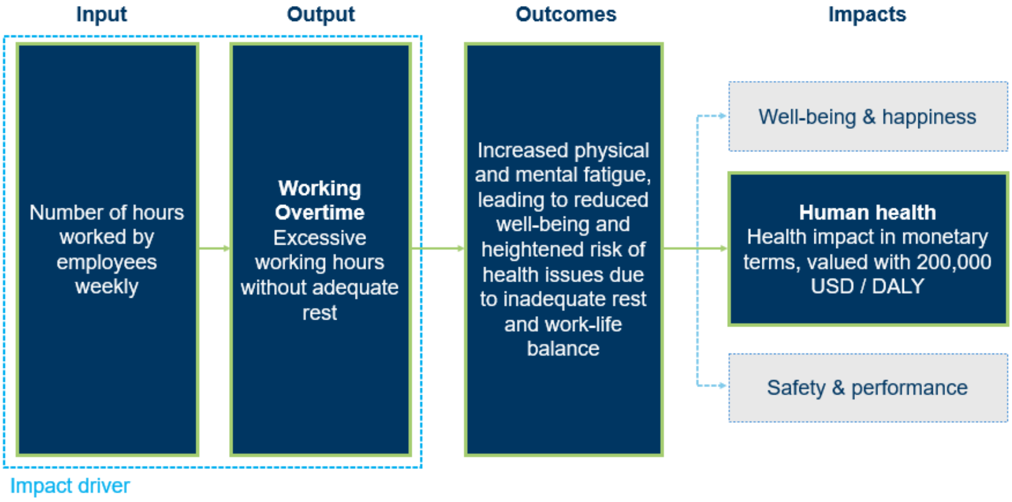

Figure 26: Impact pathway of Working Overtime (source: own illustration)

Valuation Approach

The monetization approach aims to express the negative impact that occurs due to working overtime in a monetary value. As a first step, the negative health impact related to working overtime is expressed in terms of disability adjusted life years (DALYs). The second step is a valuation of DALYs with a value of statistical life (VSL) which is supposed to capture the economic value of one year of a human life lived in a good condition of health which corresponds to USD 200,000.

The data source used is provided by the World Health Organization (WHO) and International Labour Organization (ILO) (2021b) and contains estimates of the work-related burden of disease and injury on the country level in DALYs. Related to working overtime, the database contains two causes: ischemic heart disease and stroke, which were combined.

Since the value for DALYs is only available on the country level, a distribution across all sectors is necessary. This step is done based on the number of affected employees. The DALYs per country are divided by the number of affected employees per country. This gives a value for DALYs per affected employee.

Hence, the valuation formula for each country-sector combination can be depicted as follows:

$$Working\ overtime\ impact_{c,s} = \ Affected\ people_{c,s} \times DALYs\ per\ affected\ person_{c,s} \times VSL$$

with c = country and s = sector.

The database covers 172 countries, leaving 16 missing values that were filled with regional averages that are calculated based on available data as described below.

First, all DALYs and all affected employees (physical indicator) are grouped by region, as defined by the ILO. For each of the five regions DALYs per affected employee are calculated as depicted below:

$$DALYs\ per\ affected\ employee_r = \frac{\sum_c DALYs}{\sum_c Affected\ employees}$$

with r = region and c = country.

Data gaps for the missing countries will be then filled as follows:

$$Working\ overtime\ impact_{c,s} = \ Affected\ people_{c,s} \times DALYs\ per\ affected\ employee_{r}\ \times VSL$$

with c = country and s = sector.

Assumptions

Due to a lack of sectoral differentiation in the data, the country figure of DALYs is distributed over the economic sectors according to the absolute number of affected employees per sector. We assume that regardless of the sector each employee working overtime suffers the same health effect expressed in DALYs.

The dataset contains values for 2016, 2010 and 2000. Due to the model's data requirements only the year 2016 is used. To calculate DALYs per affected employee, the DALYs from 2016 are divided by the number of affected employees from 2016 for consistency. To calculate regional averages, DALYs and affected employees are aggregated on the country level and divided. It is assumed that the DALYs per affected employee remain constant across all required years.

Future research

The approach does not cover a sector-specific consideration regarding the valuation of affected employees. Further research could determine which sectors are more likely to be related to more severe health impacts than others.

5 Value to Business - Documentation

5.1 Climate-related risks

Overview

The climate related risk indicator builds on the NGFS (Network for Greening the Financial System) scenarios (NGFS 2022) which explore the potential macro-financial impacts of climate change. These scenarios are not forecasts; rather, they outline plausible future pathways that help policymakers, regulators, and financial institutions assess and manage climate-related risks. Their purpose is not to predict what will happen, but to illuminate what could happen and what should happen, especially in the face of uncertainties surrounding climate dynamics and policy responses.

Climate-related risks fall broadly into two categories: physical and transition risks. Physical risks arise directly from the impacts of climate change. These include acute events, such as floods, storms, droughts, and heatwaves, which can cause immediate damage to property, infrastructure, and livelihoods. Chronic effects such as rising temperatures, shifting precipitation patterns, and sea-level rise unfold more gradually but can lead to long-lasting economic consequences. These impacts affect labor productivity, capital stock, and natural resources, potentially triggering persistent economic losses over time.

Transition risks, by contrast, are associated with the societal shift toward a low-carbon economy. The nature and magnitude of these risks depend on how quickly and effectively this transition occurs, which is influenced by policy and regulation, technological innovation, and consumer behavior. For example, the sudden introduction of stringent climate regulations may render fossil fuel-based assets unviable, leading to financial losses and market disruptions. On the other hand, a well-managed transition offers opportunities for investment and innovation but still requires substantial adjustment.

Below is a summary of five key NGFS scenarios we use for climate risk assessment:

Scenario	***Quadrant***	***Summary***	***Expected Warming (2100)***
Net Zero 2050	Orderly	Achieves net zero CO_2 by 2050 through stringent policies and innovation.	~1.4°C
Below 2°C	Orderly	Gradual policy tightening leads to a 67% chance of keeping warming below 2°C.	~1.8°C

NDCs	Hot House World	Fulfills all pledged national targets, even if not yet backed by policy implementation.	~2.3°C
Delayed Transition	Disorderly	Emissions remain high until 2030; transition begins abruptly, causing disruption.	~1.7°C
Current Policies	Hot House World	No new policies beyond those already implemented, leading to severe physical risks.	~3.0°C

Table 13: Five key NGFS Scenarios

Understanding how these scenarios impact the economy requires analyzing the transmission channels through which climate risks materialize. These include direct economic effects—such as damage to assets, changes in productivity, and shifts in demand—and financial system impacts like credit risk, market revaluation, and increased underwriting costs. The NGFS scenario framework integrates physical, transition, and macroeconomic models in a coherent suite, allowing users to trace how risks evolve from the climate system to the economy and ultimately to financial institutions and markets.

Transmission channels

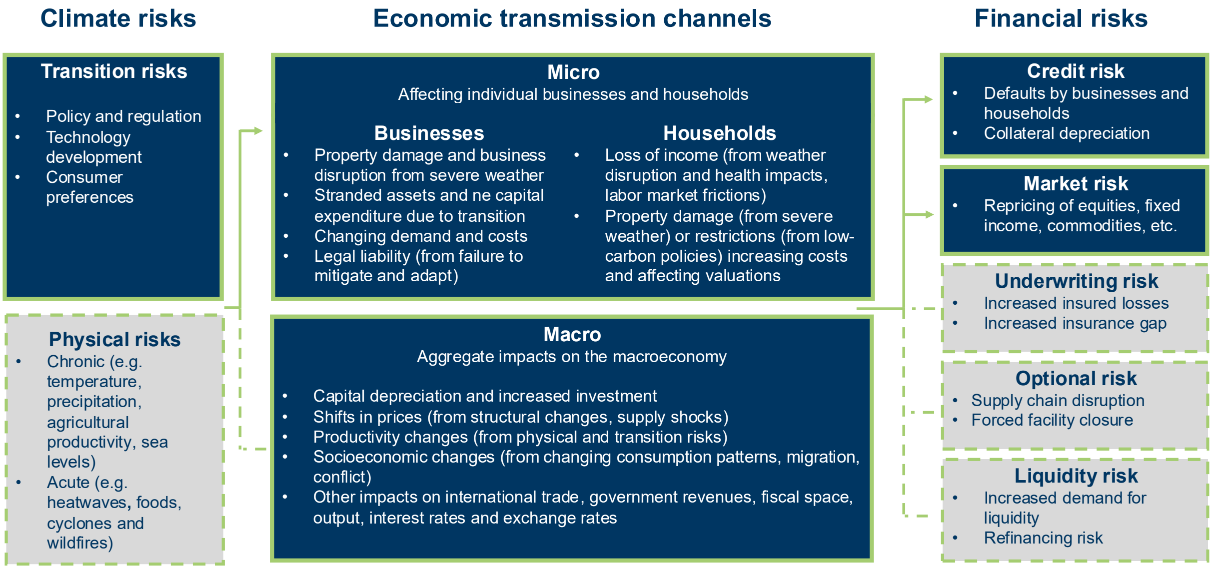

Figure 26: Transmission channels - Climate risks to financial risks (source: NGFS, own illustration). We focus on carbon taxes. Relevant transmission channels due to carbon taxes are highlighted in blue.

Our risk factors only represent those risks, which translate into a higher carbon price. The carbon price serves as a key indicator of transition risk, acting as a proxy for the stringency of climate policy, as well as shifts in technology and consumer behavior. A higher carbon price typically signals greater policy ambition in advancing climate protection objectives.

To support a transition to net-zero emissions by 2050, a substantial increase in carbon pricing would be required over the coming decade. This price represents the actual cost that must be paid per tonne of CO_2-equivalent emissions, as determined within modeled policy scenarios.

It is important to distinguish the carbon price from the **social cost of carbon (SCC)** discussed in the *Value to Society* chapter. While the SCC reflects the estimated total economic damages from an additional tonne of CO_2 emissions, carbon prices in transition scenarios capture only the portion of those damages that are internalized through policy. As a result, they are typically lower than the SCC.

The carbon price trajectories used in the NGFS scenarios are derived from the **REMIND-MAgPIE** integrated assessment model, as published on the IIASA website (REMIND Documentation, n.d.).

In Figure 26 carbon taxes are situated within the transition risk block, as they represent a direct cost signal to firms. They affect companies through increased input costs and the need for technological upgrades. Households are also impacted, as carbon taxes can lead to higher product prices and affect employment and wages in fossil fuel–dependent sectors.

At the macroeconomic level, impacts range from shifts in investment toward green technologies, to productivity effects, and broader price changes. The financial risks associated with carbon taxes primarily materialize as market risk, through the revaluation of carbon-exposed assets, and credit risk, as firms face higher risk premiums due to reduced profitability or increased default likelihood.

As we want to keep the analysis in line with the IPCC scenarios (see *WifOR Impact Valuation* documentation (Scholz et al. 2025)), we map the price scenarios of NGFS to the following IPCC-Pathways.

Risk Scenario	Emission Scenario
NGFS scenario "Below 2°C"	GHG_SSP1_26
NGFS scenario "Net Zero 2050"	GHG_SSP1_19
NGFS scenario "Nationally Determined Contributions (NDCs)"	GHG_SSP4_34 GHG_SSP5_34_OS
NGFS scenario "Delayed transition	GHG_SSP1_26
NGFS scenario "Current Policies"	GHG_SSP2_45

Table 14: NGFS Risko Scenario Mapping to Emission Scenarios

The trajectories can deviate from the physical emission paths outlined by the NGFS. However, they are qualitatively similar and have the same end-of-century GHG stock targets.

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