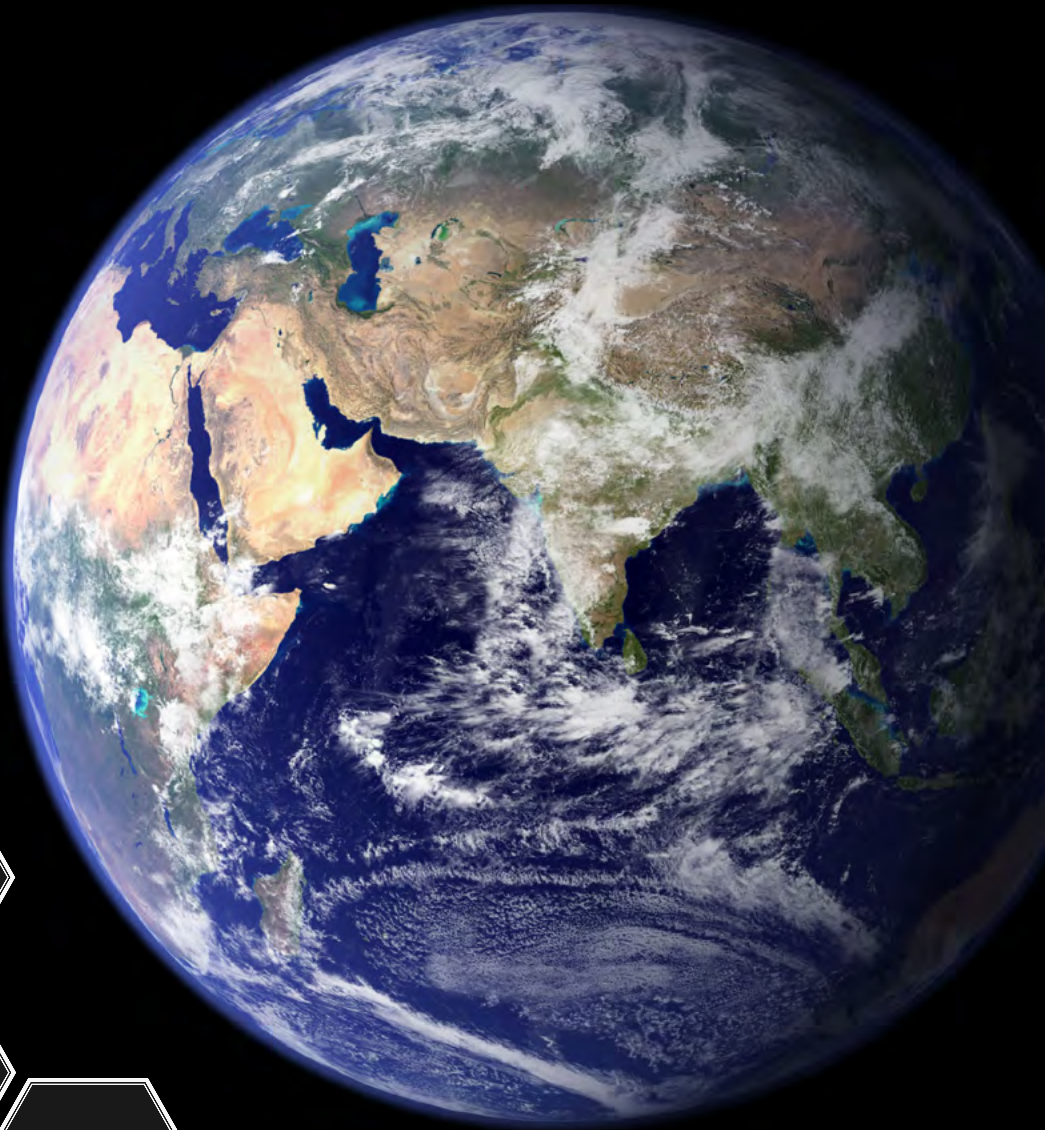
Handbook on Environmental Value Factors

Methodological Convention 4.0 for the Assessment of Environmental Impacts



German Environment Agency

Umwelt Bundesamt

Handbook on Environmental Value Factors

Methodological Convention 4.0 for the Assessment of Environmental Impacts

by

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Based on the findings of the research projects “Methodological Convention 4.0 - Principles for Updating and Extending the Methodological Convention for Estimating Environmental Costs - Part 1” and “Methodological Convention 4.0 - Principles for Updating and Extending the Methodological Convention for Estimating Environmental Costs - Part 2” as well as work by David Anthoff (Anthoff 2025).

Imprint

Publisher
German Environment Agency (UBA)
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Cover image source: Julien Jandric / Fotolia.com
(edited by Umweltbundesamt)

Publications as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 2363-832X

Dessau-Roßlau, December 2025

The responsibility for the content of this publication lies with the authors.

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1 Introduction

The value factors presented in this handbook are based on research of the German Environment Agency (UBA) and the results of the following research projects:

- Methodological Convention 4.0 - Principles for Updating and Extending the Methodological Convention for Estimating Environmental Costs - Part 1 (Osterwald et al. 2024)
- Methodological Convention 4.0 - Principles for Updating and Extending the Methodological Convention for Estimating Environmental Costs - Part 2 (Walther et al. 2024a)
- Extension of the GIVE model to include equity-weighting and emission years beyond 2025, including for methane and nitrous oxide (Anthoff 2025)

The relevant parts of these research projects are referenced in the respective chapters of this handbook. The research reports are available upon request (Bjoern.Buenger@uba.de, Nadia.Eser@uba.de, Astrid.Matthey@uba.de).

Value factors translate environmental impacts into monetary terms and can, in principle, be based on three cost concepts:

1. *Damage costs* specify the loss incurred by individuals or society as a consequence of environmental impacts such as pollution, land-use change or greenhouse gas emissions.
2. *Mitigation or abatement costs* specify the costs that arise from reducing environmental pressures (emissions etc.) to avoid harmful environmental impacts
3. *Restoration costs* specify the costs that arise if damages are repaired and the original state of the environment is restored.

The value factors in this handbook pursue the goal of assessing the impacts or damages that society incurs due to environmental pollution or land degradation, expressed in monetary terms. We therefore use the damage cost approach throughout. We generally refrain from using the mitigation or restoration cost approach as a proxy for damage costs to close data gaps, because:

- Mitigation costs depend on a mitigation target. The less ambitious the target, the lower the mitigation cost value factors. Environmental impacts that are estimated based on mitigation costs, therefore, appear lower the less ambitious the mitigation policy, although the environmental effects of non-mitigated impacts are the same. In addition, mitigation costs, being themselves dependent on a mitigation target, cannot be used to derive policy targets.
- Restoration costs can be real or virtual. If restoration is real and complete, there remains no impact to be valued. If restoration is virtual, the impact persists until restoration actually takes place, if ever. Hence, for the duration of the impact, restoration is no meaningful proxy, also because there is no general correlation between the size of an impact and the costs of its restoration.

We base our analysis of impact pathways on the Drivers-Pressures-States-Impacts-Responses (DPSIR) framework introduced by the European Environment Agency (EEA)[1]. Within this framework, our work focuses on the link between Pressures and Impacts.

The value factors in this handbook are average values for emissions and economic activities in Germany, which can, however, also have an effect abroad. This particularly applies to damages caused by greenhouse gas emissions. Emissions of classical air pollutants and noise cause damages of varying geographical range depending on the emission context. If the environmental impacts are to be estimated for specific local circumstances, the value factors should be adjusted to the respective circumstances where possible. Average values can only provide an approximation. To apply the value factors outside Germany, they should be adjusted to the respective income level, and local conditions like population density, background emissions etc. as appropriate.

Please note that the value factors in this handbook are estimates. They represent approximate rather than exact figures, showing the order of magnitude of the environmental impacts. Accordingly, most of the value factors are rounded. However, in some sectors the valuation of environmental impacts tends to involve larger quantities, like millions of kilometres driven or kilowatt-hours generated. For these sectors, we have decided to round no further than to two decimal places to avoid an excessive accumulation of rounding errors.

All value factors presented in this document are adjusted to the price level of 2025. For an application of the value factors to activities or emissions after 2025, a price adjustment is required. For this purpose, we recommend adjusting the value factors with the consumer price index of the respective National Statistical Office.

We dedicate this publication to Daniel Sutter, our esteemed colleague from INFRAS, who contributed massively to our research on this topic for more than a decade. Daniel was also part of the research projects this work is based on. He sadly passed away before the completion of this handbook.

[1] "According to this systems analysis view, social and economic developments [Drivers] exert Pressure on the environment and, as a consequence, the State of the environment changes, such as the provision of adequate conditions for health, resources availability and biodiversity. Finally, this leads to Impacts on human health, ecosystems and materials that may elicit a societal Response that feeds back on the Driving forces, or on the state or impacts directly, through adaptation or curative action", EEA (1998, p. 6).

2 Emission of Greenhouse Gases

2.1 Value Factors for Carbon Dioxide and other Greenhouse Gas Emissions

Greenhouse gas emissions not only contribute to global warming but also result in significant economic damages due to the impacts on ecosystems, infrastructure and human health. We recommend using a value factor of 990 $€_{2025}$ / t for CO_2-equivalent (CO_2-eq) emissions occurring in 2025 when weighting the welfare of current and future generations equally (0% pure rate of time preference). When placing a higher weight on the welfare of current compared to future generations (1% pure rate of time preference), we recommend a value factor of 345 $€_{2025}$ / t CO_2-eq.[2] In addition, we recommend a sensitivity analysis with the respective other value.

The recommendations follow the Social Cost of Carbon approach (damage cost concept) and are based on the Greenhouse Gas Impact Value Estimator (GIVE) model. The original GIVE model (Rennert et al. 2022) was adapted for this handbook as follows (for details see Section 2.2 Methodological Background):

- Use of equity weighting to account for impacts in different world regions[3];
- Use of two different time preference parameters: a pure rate of time preference (PRTP) of PRTP=0%, which reflects an equal weight of the welfare of future and present generations, and a PRTP of 1%, which reflects a considerably lower weight on the welfare of future generations (with PRTPs being different from discount rates);
- Use of the Value of a Statistical Life (VSL) based on Amann et al. (2020a). This is consistent with the value factors on air pollutant and noise emissions in Chapters 2 and 5;
- Use of the consumer price index of the German Federal Statistical Office to adjust prices from the base year of the GIVE model 2005 to 2025[4];
- Use of OECD purchasing power parities for currency conversion from USD into EUR[5].

[2] See Section 2.2 Methodological Background for further information on the pure rate of time preference and discounting.
[3] Prest et al. (2024), Anthoff (2025).
[4] Destatis (2025). When stating $€_{2025}$ or price level of 2025 this means that the price development (inflation) has been taken into account up until the end of 2024.
[5] OECD (2024).

For greenhouse gas (GHG) emissions in 2020 as well as years beyond 2025, the GIVE model yields the following recommendations, which are adjusted for the above-mentioned parameters:

Table 1: Value factors for greenhouse gas emissions in €$_{2025}$ / t GHG

Year of emission	Social Cost of Greenhouse Gases in €$_{2025}$/t GHG					
	CO_2 / CO_2-eq		CH_4		N_2O	
	0% PRTP	1% PRTP	0% PRTP	1% PRTP	0% PRTP	1% PRTP
2020	935	310	7,770	4,580	260,900	105,700
	…	…	…	…	…	…
2025	**990**	**345**	**9,220**	**5,800**	**282,300**	**118,700**
2026	1,000	350	9,510	6,040	286,600	121,300
2027	1,010	355	9,790	6,290	290,900	123,900
2028	1,020	365	10,080	6,530	295,200	126,500
2029	1,040	370	10,370	6,780	299,500	129,100
2030	1,050	375	10,660	7,020	303,800	131,700
	…	…	…	…	…	…
2040	1,150	440	14,200	9,950	339,900	154,500
2050	1,240	485	16,580	12,100	355,400	167,800

Please note that the value factors in this table, as well as all value factors in this handbook, are estimates that show the order of magnitude of the environmental impacts, rather than exact figures.
Source: Adapted GIVE model (Anthoff 2025) and own calculations.

When using these value factors, the following guidance applies:

- To obtain value factors for years for which no figures are given in Table 1, we recommend linear interpolation between the indicated value factors.
- For a price adjustment of the value factors, we recommend using the consumer price index[6].
- Table 1 recommends value factors for the greenhouse gases carbon dioxide (CO_2), methane (CH_4) as well as nitrous oxide (N_2O). When detailed information on the emission of these three greenhouse gases is available, we recommend using the respective value factors. If, however, data is only available on the emission of CO_2-equivalents, we recommend using the CO_2 value factors as a proxy[7].
- The Global Warming Potential (GWP as per IPCC recommendation[8], time horizon 100 years) can be used to transfer the value factors of carbon dioxide to greenhouse gases not

[6] For Germany, see Destatis (2025).
[7] Many databases provide emission factors as CO_2-equivalents. This means that all greenhouse gas emissions are translated into units of CO_2 by using Global Warming Potentials (GWP), most commonly the GWP100, which has a time horizon of 100 years. These GWP values express the Global Warming Potential of different greenhouse gases relative to CO_2, i.e. in so called CO_2-equivalents; CO_2 thus has a Global Warming Potential of 1. See UBA (2022a) for further information.
[8] Cf. IPCC AR6 (2022), or IPCC AR7 upon publication.

included in the above table or to translate emission data for other greenhouse gases into CO_2-equivalents.

- When using the above value factors to assess the impacts of greenhouse gas emissions in the aviation sector, it is important to note that combustion processes develop a higher damage potential at high altitudes[9]. The specific emission weighting factor for individual flights depends on a range of parameters, such as the time and location of the emissions and the weather conditions, and can vary substantially. If no specific value for the emission weighting factor for individual flights is available, an emission weighting factor of 3 can be used as an approximation (UBA 2025c).

2.2 Methodological Background

2.2.1 Cost Concept - Damage Cost vs. Mitigation/Abatement Cost Approach

As explained in the introduction, we use the damage cost approach throughout this handbook to reflect the impacts of environmental pressures. In the context of greenhouse gas emissions, this means we use a concept usually referred to as Social Cost of Carbon (SCC) that assesses the impacts or damages that occur worldwide as a consequence of greenhouse gas emissions.

In other contexts, the mitigation or abatement cost approach may be more suitable. The abatement cost approach estimates the cost of (technical or behavioural) measures necessary to reach a pre-determined emission reduction target, for example based on national policy or a company strategy. Since mitigation costs are based on a specific reduction target, they cannot be used to derive such a target, or to value impacts.

2.2.2 GIVE Model

Climate costs in previous versions of this handbook were based on the SCC estimates of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model by Anthoff (2007). In the current version, we use SCC estimates of the successor model GIVE, which was introduced in 2022. While FUND estimated SCC for emissions of CO_2 equivalents, GIVE additionally directly models estimates for the impacts related to the emission of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O). This is an advantage compared to first converting emissions into CO_2-equivalents using Global Warming Potential (GWP) coefficients[10], and then valuing emissions based on CO_2-equivalent value factors as GWP100 normalizes all impacts to an atmospheric lifetime of 100 years. This can lead to distortions when assessing the impacts of nitrous oxide and methane, as the atmospheric lifetime of these greenhouse gases is different from CO_2. These distortions can be avoided through the direct modelling of methane and nitrous oxide emissions implemented in the GIVE model.

The GIVE model is an open-source integrated assessment model used to compute SCC. In a first step, projections regarding the economic and demographic development serve as predictors of a future greenhouse gas emissions pathway. Secondly, the projected GHG emissions pathway is fed into a climate module[11], which can then be used to model GHG concentrations, temperature increases and sea level rise[12]. Finally, the modelled impacts of climate change on different sectors are monetized, aggregated and converted into a present value by means of discounting. The model

[9] UBA (2023a).
[10] GWP100 of 273 for nitrous oxide, 27 for non-fossil methane and 29.8 for fossil methane, all according to IPCC AR6 (2022).
[11] Finite Amplitude Impulse Response (FaIR) model, see Smith et al. (2018).
[12] Building blocks for Relevant Ice and Climate Knowledge (BRICK), see Wong et al. (2017).

is stochastic, results (distributions) are obtained from a large number of model runs (Monte Carlo).

In contrast to older models, GIVE accounts for uncertainties of individual components as well as across the overall modelling process, enabling a consistent assessment of the impacts associated with marginal GHG emissions. The better understanding and integration of uncertainty and other components relevant for estimating climate damage costs as well as improved projections of economic and demographic developments result in higher SCC estimates than those from older models.

The damage module deployed in GIVE comprises four impact categories: agriculture, health (through heat related mortality), building energy consumption and sea level rise. Climate damage costs in the impact categories health, energy consumption and sea level rise are available at the country-level, whereas in the agricultural sector they are only available for 16 world regions. In the central estimate in Rennert et al. (2022), which does not implement equity-weighting, the increased heat related mortality due to climate change contributes 49% to the total social costs of CO_2-eq, while agricultural damages make up for 45% percent, followed by a contribution of energy consumption of around 5% and damages from sea level rise that only amount to 1% of the overall climate damage costs. The neglectable impact of rising sea levels on the climate damage costs is mainly due to the fact that significant damages from sea level rise occur further in the future, thereby implying that the effects of discounting are strongest for this impact category. The small contribution of sea level rise to overall climate damage costs is also rooted in the model used for this impact category (Coastal Impact and Adaptation Model (CIAM)). The model optimizes the adaptation strategy, thereby presumably entailing only small costs that may not be in line with the actual, real-world costs of adapting to rising sea levels and the costs of sub-optimal adaptation (Rennert et al. 2022).

By aggregating the climate damage costs over four impact categories, GIVE covers a range of climate change effects. However, it is crucial to note that a large number of impact categories and effects are not or not fully considered, such as tipping points, migration, conflict, impacts on biodiversity, extreme weather events or labor productivity. The integration of these and other impacts into the model framework is likely to substantially increase the climate damage cost estimates, see, e.g., recent work by Bilal and Känzig (2024). Furthermore, even the impact categories that are considered, do not cover the whole range of climate damages occurring in the respective sectors, e.g. health impacts only comprise heat-related mortality increases but do not consider morbidity effects, and, as detailed above, the costs of adapting to rising sea levels are likely to be much higher than predicted using CIAM. Keeping in mind that a multitude of the impacts brought about by climate change are not or not comprehensively considered in GIVE, the climate damage costs presented in this chapter must be viewed as very conservative estimates which are likely to gravely underestimate the actual damage caused by the emission of greenhouse gases. Improving the data base to include further impacts and/or basing estimates on the precautionary principle must be expected to increase damage costs by at least an order of magnitude.

2.2.3 Discounting and the Pure Rate of Time Preference

The time at which the costs and benefits of today's decisions materialize plays an important role in economic analyses. To compare present and future costs and benefits, future outcomes are discounted to the present day using a discount rate. This discount rate is to reflect two aspects: (1) individual or societal time preference and (2) the relative change between present and future prices of different goods and services.

1. The time preference, captured in the Pure Rate of Time Preference (PRTP), reflects the degree to which individuals or society as a whole prefer or value present goods and services over future ones.

   When valuing private goods at an individual level, a positive time preference is commonly assumed, that is, a preference for obtaining goods like income or consumption goods earlier rather than later. However, government decision making often concerns public goods. Many of the impacts on public goods only materialize in the distant future, e.g. the long-term health impacts of air pollution or impacts of greenhouse gas emissions that remain in the atmosphere for decades or centuries. Such long-term impacts affect individuals that do not make decisions today, e.g. children or future generations. Placing a lower value on the preferences of these individuals compared to those of decision makers today raises questions from an intergenerational welfare perspective.

   When used in economic models, a PRTP of 0% reflects the normative assumption that the utility ("welfare") of future and present generations should be weighed equally. In contrast, a PRTP>0 reflects the normative assumption that the utility of present generations should be weighed higher than that of future generations[13]. Numerically, a PRTP of 1% means that in intergenerational comparison only 74% of the utility (welfare) in 30 years' time is taken into account, and only 55% of the utility in 60 years' time. With a PRTP of 3%, these values drop to 41% and 17%, respectively.

2. The usual assumption for goods and services included in GDP and consumption measures is to become more abundant in the future (GDP and consumption are expected to grow). Hence, their relative prices are expected to fall compared to goods and services that are expected to remain constant or become relatively scarcer in the future (e.g., many ecosystem services).

In the GIVE model we use the social discount rate developed by Frank Ramsey (Ramsey 1928), which combines the two elements above: i) expected consumption growth, weighted by its effect on the marginal utility of consumers, and ii) the pure rate of time preference (PRTP).

Technically, in GIVE the consumption growth rate is a dependent variable and hence varies throughout the model runs (Monte Carlo). Therefore, it is not possible to specify the exact discount rate used for the climate costs presented in this chapter. However, the Pure Rate of Time Preference is kept constant over the Monte Carlo runs, and results are presented for a PRTP of 0% and 1%.

Given the above, two additional aspects need to be considered:

- Relative prices for consumption goods are expected to decrease, increasing the discount rate for these goods and services. In contrast, the provision of many ecosystem services is in decline due to habitat degradation, climate change and biodiversity loss. Accordingly, for the economic valuation of most environmental impacts there is a consensus that a lower discount rate must be applied, to account for an increase in relative scarcity of benefits provided by ecosystems, which results in relative price increases (see, e.g., Drupp et al, 2024). Even if environmental degradation was to be stopped, rising incomes would cause ecosystem services to become relatively scarcer and, thus, would induce an increase in the willingness-to-pay (WTP) for them (income effect). However, if the provision of ecosystem services continues to decline as indicated by many ecological indicators (e.g. IUCN red list species, forest cover loss, Living Planet Index, ecosystem intactness index),

[13] A PRTP<0% would place a higher weight on the utility of future compared to present generations, but is not known to be used.

the WTP for ecosystem services would rise even further (scarcity effect) (Drupp et al. 2024, Baumgärtner et al. 2015), implying an even lower discount rate.

- In business decisions, which are based on individual preferences, it is common to use a market interest rate to discount future costs and benefits. This market interest rate represents the opportunity cost of capital. The idea behind this is that at this interest rate, future costs can be offset by capital invested today. It rests on the assumptions that i) invested capital and future costs apply to the same economic entity and ii) costs follow the same general market trend as financial returns. For public policy decisions, however, the market interest rate is not the appropriate concept. First, given the temporal, geographical and social distance of the consequences of many public policy decisions, investment returns cannot be ensured to be made available to those bearing the costs. Second, basic welfare components like ecosystem services do not necessarily follow the market trend (in terms of prices and volumes, see, e.g. point 1 above.) In addition, since the monetization of environmental impacts is based on a marginal utility concept, the discount rate has to account for limitations in the link between the marginal utility of those affected and financial markets, e.g., affected communities not having access to financial markets at all. Finally, and related to the limitations above, the discount rate for public policy decisions has to account for higher social risk aversion and for long-term governmental goals such as intergenerational equity and long-term social welfare.

2.2.4 Equity Weighting

The UBA has advocated for the use of equity weighting since the first edition of this handbook "Methodological Convention 1.0" in 2007, to take equal account of the welfare effects on all humans. With equity weighting, the damages caused by greenhouse gases emitted in Germany but occurring in different parts of the world are weighted with the respective ratio of average incomes (see box *Equity Weighting*). We thus value the damage costs caused by one (metric) tonne of GHG as if they were incurred (entirely) in Germany, or rather as if the whole world had the same income level as Germany. Differences in income within Germany are not considered, i.e. the damage is valued as if climate impacts affect the poorer and richer parts of the population equally.

It would not be necessary to use equity weighting when calculating climate costs if the affected parties were actually being compensated immediately by the parties causing the damage. However, this is not a realistic assumption, neither for interregional nor for intertemporal compensation. Equity weighting is therefore required to ensure that the social costs of carbon value the impacts of emissions on the quality of life of the affected people (the "utility" or "welfare" in economic terms) rather than only nominal income losses.

Background and Application of Equity Weighting

The effects of climate change are global, they occur irrespective of where greenhouse gases are emitted. Accordingly, every tonne of greenhouse gas which is emitted in Germany results in damages all around the world.

However, due to the differences in economic wealth across the globe, comparable damages correspond to different nominal monetary values. If, for example, residential buildings are destroyed by extreme weather events, their material value is on average higher in richer countries than in poorer countries. However, the people in poorer countries are at least as much affected in terms of their quality of life (their "utility" or "welfare" in economic terms) as people in richer countries, often even more so, due to the lack of insurance and government aid. It is true that it is also nominally cheaper to restore the damage incurred (e.g. repairing buildings and the infrastructure) in poorer countries. But the resulting loss of utility per monetary unit that is used for the repairs – and hence cannot be used for other purposes – is also greater. These differences in wealth can be accounted for in the assessment of global climate damage by using equity weighting. Using German equity weights thus means that we estimate costs as if all damages caused by one tonne of GHG were incurred entirely in Germany, or rather as if the whole world had the same income level as Germany.

With equity weighting, the nominal monetary values of the damages are weighted by the average income of the country in which they occur. If climate change causes assumed damage of 1€ in a country which has an average income of 500€ per capita, the damage amounts to 1/500 of the per capita income. However, if the same damage occurs in a country with an average income of 5,000€, this damage would only represent 1/5,000 of the per capita income. Thus, in relation to income, the damage in the richer country is less severe. Equity weighting means weighting the damage in accordance with the average income. If the per capita income in a poor country is 10 times less, the nominal damage costs are weighted 10 times higher.

3 Emission of Air Pollutants

3.1 Average Value Factors for Air Pollutant Emissions

Air pollutant emissions lead to substantial environmental and health impacts, which translate into significant economic costs. The value factors displayed in this chapter are based on the work by van der Kamp et al. (2024) and own calculations. They incorporate impacts on health (mortality and morbidity), crops, and materials & buildings[14] and are based on the following aspects (see Section 3.4 for further methodological background):

- The value factors relate to emissions of air pollutants in Germany, not immissions, and are given as average costs per emitted unit of air pollutant. This serves the purpose of making the value factors more usable for practical applications such as cost-benefit analyses, as it allows to link specific emissions of air pollutants with the resulting (monetized) impacts.
- The value factors reflect the price and income (proxied by GDP per capita) levels for Germany in 2025.
- The air quality and exposure to air pollutants is modelled using EcoSenseWeb, a model developed for the EU project NEEDS (New Energy Externalities Development for Sustainability), Version v1.3 (Preiss et al. 2008). The exposure-response functions are largely based on the HRAPIE (Health Risks of Air Pollution In Europe) project, with one exception: For the mortality risk from long-term exposure to particulate matter, we use the exposure-effect relationship from Chen and Hoek (2020).
- The monetary valuation of health impacts is based on Amann et al. (2020a), whereas the valuation of non-health related impacts is based on data from the NEEDS project as well as response functions in Mills et al. (2007) to assess impacts on crops.
- The values factors for NO_x, SO_2 and NH_3 do not assess the direct effects of these pollutants but only capture their impacts through secondary particulate matter formation.

Table 2 shows the average value factors per emitted tonne of the respective pollutant[15] for emissions from "unknown sources"[16] in Germany. These average values can be used for a rough estimate of the impacts caused by air pollutants if no specific information on the emission source is available.

[14] In previous versions of this handbook, biodiversity losses from air pollution based on the NEEDS project were also incorporated. However, given the difficulties in assessing biodiversity impacts, we have decided to no longer include these impacts. Consequently, the value factors should be interpreted as rather conservative estimates of the actual impacts of air pollution. See chapter 9 for a more detailed explanation.

[15] The most important air pollutants in this context are particulate matter (PM), nitrogen oxides (NO_x), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOC) and ammonia (NH_3).

[16] Unknown source (unknown height of release) means that there is no specification regarding the stack height of the respective emission source plant. Consequently, these are average values. The impacts increase with decreasing height of the emission source, i.e. emissions from low emission sources (plants with low stack heights) lead to more pronounced impacts than those from higher emission sources.

Table 2: Average value factors for air pollutants emitted by unknown sources (in €2025 /t)

	Value factors for emissions in Germany in $€_{2025}$/t emission			
	Health impacts	**Crop impacts**	**Material/Building impacts**	**Total**
$PM_{2.5}$	128,200	-	-	128,200
PM_{coarse}	1,690	-	-	1,690
PM_{10}	90,200	-	-	90,200
NO_x	36,000	1,530	210	37,740
SO_2	34,500	-140	965	35,325
NMVOC	525	1,450	-	1,975
NH_3	30,400	-125	-	30,275

Assumption: PM_{10} consists of 70% $PM_{2.5}$ and 30% PM_{coarse}. For NH_3, NO_x and SO_2, the value factors only reflect the impacts from secondary particulate matter formation. The negative values for crop impacts derive from fertilization effects. These effects are under scrutiny as they may be linked to a loss of quality in the affected crops.
Source: Van der Kamp et al. (2024) and own calculations.

3.2 Differentiated Value Factors for Air Pollutant Emissions from Different Sources

The adverse impacts of air pollutants on human health tend to increase as the height of the emissions source decreases and the population density around the emission source increases. Therefore, the value factors per tonne of emissions vary as a function of these factors. This differentiation is primarily relevant for the value factors for particulate matter, while the value factors for the other air pollutants show little variation with regard to the release height and location. Thus, for most applications it is sufficient to use average value factors. However, if site-specific valuations are needed or the share of particulate matter emissions is relatively high, the application of differentiated value factors can generate additional insights.

Table 3 shows the health-related value factors from the emission of air pollutants through power generation as well as industrial and small-scale combustion plants for Germany. The monetized health effects are differentiated by release height (power stations (>100m), industrial power generation (20-100m) and small-scale combustion plants (0-20m)) as well as location of the emission source (metropolitan areas (city) and urban areas (town)).

No differentiation according to sector, surroundings and release height is made for the value factors relating to crop and material/building impacts (shown in Table 2). They remain constant regardless of these parameters and should be added to the differentiated value factors for health impacts (in Table 3).

Table 3: Health-related value factors for air pollutants emitted by power stations, combustion processes in industry and small-scale combustion plants (in €2025 / t)

Value factors for health impacts in $€_{2025}$/t emission											
Sector:	**Power stations**	**Combustion processes in industry**					**Small scale combustion facilities**				
Surroundings:	**Unspecified**	**Unknown**	**City**		**Town**		**Unknown**	**City**		**Town**	
Emission height (in m):	**>100**	**0-100**	**0-20**	**20-100**	**0-20**	**20-100**	**0-100**	**0-20**	**20-100**	**0-20**	**20-100**
$PM_{2.5}$	66,900	137,400	245,900	138,700	170,300	138,700	130,300	233,200	131,600	161,500	131,600
PM_{coarse}	745	1,870	3,350	1,890	2,320	1,890	1,690	3,030	1,710	2,100	1,710
PM_{10}	47,000	96,700	173,100	97,700	119,900	97,700	91,700	164,100	92,600	113,700	92,600
NO_x	28,800	38,100	38,100	38,100	38,100	38,100	39,400	39,400	39,400	39,400	39,400
SO_2	31,800	35,600	35,600	35,600	35,600	35,600	35,900	35,900	35,900	35,900	35,900
NMVOC	530	535	535	535	535	535	530	530	530	530	530
NH_3	33,300	33,200	33,200	33,200	33,200	33,200	33,100	33,100	33,100	33,100	33,100

Categories "city" and "town" differ according to municipality size (city >100,000, 2,000<town<100,000)

Assumption: PM_{10} consists of 70% $PM_{2.5}$ and 30% PM_{coarse}. This assumption should be adjusted if source-specific composition information is available. For NH_3, NO_x and SO_2, the value factors only reflect the impacts from secondary particulate matter formation.

Source: Van der Kamp et al. (2024) and own calculations.

3.3 Value Factors for Air Pollutant Emissions from Road Traffic

As stated above, the severity of health impacts is inversely related to the height of the emission source, i.e. the lower the emission release height, the graver the health impacts tend to be. Consequently, the health impacts from road traffic are particularly severe and require special attention, given the close proximity of the emission sources, in the form of vehicles (release height 0-3m), to human receptors. This effect is particularly pronounced for particulate matter emissions. The effect is even more aggravated in metropolitan areas with high population density, where a larger number of human receptors coincides with heavier road traffic, thereby further intensifying the adverse effects on human health. To account for this difference in the severity of health impacts in different surroundings, the value factors are adjusted using a factor that reflects the different population densities in the respective surroundings (urban, suburban, rural).

No differentiation according to surroundings is made for the value factors relating to crop and material/building impacts (shown in Table 2). They remain constant regardless of surroundings and should be added to the differentiated value factors for health impacts (in Table 4).

Table 4: Health-related value factors for air pollutants emitted by transport (in €$_{2025}$ / t)

	Value factors for health impacts in €$_{2025}$/t emission			
Surroundings:	**Unknown**	**Urban**	**Suburban**	**Rural**
$PM_{2.5}$	125,900	511,600	147,500	86,600
PM_{coarse}	1,600	7,800	1,940	960
PM_{10} abrasion	63,800	259,700	74,700	43,780
NO_x	37,100	37,100	37,100	37,100
SO_2	34,600	34,600	34,600	34,600
NMVOC	525	525	525	525
NH_3	32,100	32,100	32,100	32,100

The categories Urban, Suburban and Rural differ according to population density (Urban > 1,500 / km^2, 300/ km^2< Suburban <1,500/ km^2, Rural < 300/ km^2).
Assumptions on composition of particulate matter: For abrasion from tires, brakes and roads, we assume that PM_{10} consists of 50% $PM_{2.5}$ and 50% PM_{coarse}. For exhaust emissions from road traffic, it is assumed that $PM_{2.5}$ makes up 100% of PM_{10}, thus the respective value factors for $PM_{2.5}$ can be used.
For NH_3, NO_x and SO_2, the value factors only reflect the impacts from secondary particulate matter formation. The negative values for crop impacts derive from fertilization effects. These effects are under scrutiny as they may be linked to a loss of quality in the affected crops.
Source: Van der Kamp et al. (2024) and own calculations.

3.4 Methodological Background

For the air quality and exposure modelling we use the EcoSenseWeb model developed for the EU project NEEDS (New Energy Externalities Development for Sustainability), Version v1.3 (Preiss et al. 2008), that has already been used in previous versions of this handbook (Methodological Conventions 2.0, 3.0 and 3.1, cf. e.g. UBA (2023c)). EcoSenseWeb is an integrated atmospheric dispersion and exposure assessment model to calculate external costs of air pollution focused on human health impacts (University of Stuttgart 2024). It is based on the European Monitoring and Evaluation Programme (EMEP) model. Due to decreasing emission levels in Germany, the EcoSenseWeb emission scenario for the year 2020 is used for this update of the handbook, as opposed to the 2010 emission scenario that has been used for previous versions. While more recent findings for modelling the atmospheric dispersion of emissions within the EMEP model are available, these are not taken into account in the currently available version of EcoSenseWeb and can therefore not be used to estimate the value factors. Besides health impacts, the value factors for the emission of air pollutants also include impacts on crops and building materials. Where possible, impacts on crops were assessed on the basis of the response functions in Mills et al. (2007). For the remaining air pollutants as well as for impacts on building material, the value factors were derived from updated NEEDS data.

For the update of this handbook, the assessment of health impacts of air pollutants largely follows the recommendations in Amann et al. (2020b) to maintain the exposure-response functions from the HRAPIE (Health Risks of Air Pollution In Europe) project with one exception: For the mortality risk from long term exposure to particulate matter, we use the exposure-effect relationship from Chen and Hoek (2020). The exposure-response functions from HRAPIE and Chen and Hoek (2020) are entered into a simplified computation framework that yields the increase in years of life lost (YOLL) from increased air pollutant concentrations. In comparison to the previous version of this handbook, the computed YOLL are around 30% higher, thereby significantly driving the increase in value factors for the emission of most of the air pollutants. For the monetization of health impacts from exposure to air pollutants, we use the figures on mortality and morbidity from Amann et al. (2020a). For almost all health endpoints assessed in Amann et al. (2020a), the monetized health impacts have considerably increased in comparison to the previous version of this handbook. These two effects, i.e., the increase in YOLL in combination with higher values for monetized health impacts entail a significant overall increase for most of the value factors for the emission of air pollutants. They outweigh the dampening effect of lower emission levels of air pollutants that is reflected in the use of the 2020 scenario in EcoSenseWeb.

As Amann et al. (2020a) point out, many research projects continue to rely on the HRAPIE exposure-response functions and results, sometimes extending them by additional health effects. However, the continued reliance on the HRAPIE exposure-response functions tends to lead to an underestimation of air pollution related health impacts (Amann et al. 2020a). Furthermore, it is still not possible to quantify the impacts from direct NO_2 exposure, thereby leading to an underestimation of the impacts per tonne of NO_2 emitted. The value factors for the emission of air pollutants detailed in the tables in this chapter should therefore be viewed as conservative estimates that are likely to underestimate the actual impacts of air pollutants on human health.

The value factors for air pollutants are specified as average costs per emitted unit. This reflects the general focus of this handbook on making the value factors usable for practical applications like cost-benefit analyses, in this case by linking specific emissions of air pollutants to resulting (monetized) impacts. This application perspective is also why the value factors on air pollutants draw on emissions rather than immissions: It is often easier to quantify the emissions from individual plants, projects, legislative proposals etc. than the associated immissions. The relationship between emissions and immissions is modelled as part of the impact pathway approach (DPSIR, see Introduction).

The values provided in Table 2 through Table 4 are given in 2025 prices and incorporate the income development in Germany up until 2025. In the original source, Amann et al. (2020a), the monetary values are given in $€_{2005}$ and apply to the EU27 area rather than Germany specifically. To reflect the present value of the Euro, the price level changes in Germany between 2005 and 2024 have been taken into account. We used the consumer price index of the German Federal

Statistical Office to convert the value factors to €$_{2025}$[17]. To account for the difference in purchasing power between the EU27 average and Germany, the monetary values are corrected for Germany using GDP per capita levels as a proxy for purchasing power[18]. We have further considered that the willingness to pay for avoiding immaterial health impacts (pain and suffering) increases with income. Therefore, the value factors are adjusted for changes of the gross domestic product per capita in Germany between 2005 and 2025 (including the use of an elasticity figure of 0.85, which is based on the NEEDS project and reflects the assumed increase in willingness to pay with income)[19].

[17] Destatis (2025). When stating €$_{2025}$ or price level of 2025 this means that the price development (inflation) has been taken into account up until the end of 2024.

[18] Eurostat (2025).

[19] Eurostat (2025).

4 Power and Heat Generation and Refrigeration

4.1 Value Factors for Electric Power Generation

The environmental impact of electric power generation strongly depends on the power generation technology deployed, i.e. the energy source used to produce electricity. Generally, it can be stated that the environmental costs per unit of electric power (kilowatt hour) are significantly lower for renewable than for fossil energy sources. The value factors in this chapter are based on the work by Walther et al. (2024b), van der Kamp et al. (2024) and Anthoff (2025).

A more detailed description of the methodology can be found in Section 4.4. The following provides an overview of some important aspects with respect to the value factors in Table 5:

- Emission factors for direct and indirect emissions as well as the value factors for greenhouse gases and air pollutants presented in Chapters 2 and 3 were used to determine the value factors in this chapter.
- The value factors in this chapter capture environmental impacts from the emission of greenhouse gases and air pollutants related to electricity generation. Other environmental impacts, such as impacts on ecosystems and biodiversity through land use change or pollution, are not accounted for.
- All values are average value factors for electric power generation in Germany; if the aim is a site specific, differentiated assessment, information and assumptions on the locations of the power generation facilities as well as their specific emissions are required.

Two value factors are provided for each energy source – one using a 0% Pure Rate of Time Preference (PRTP) and one using a 1% PRTP for GHG emissions (see Section 2.2 for further information).

Table 5: Value factors for electricity generation in Germany including upstream supply chains in €-cent$_{2025}$ / kWh$_{el}$

Value factors for electricity generation in €-cent$_{2025}$/kWh$_{el}$					
Electric power generation from	**Air pollutants**	**Greenhouse gases (1% PRTP)**	**Greenhouse gases (0% PRTP)**	**Total environmental impacts (1% PRTP)**	**Total environmental impacts (0% PRTP)**
German electricity mix 2024*	2.23	11.56	32.53	13.79	34.76
Fossil energy sources					
Lignite	3.93	35.89	103.34	39.82	107.27
Hard coal	4.82	29.08	82.26	33.90	87.09
Natural gas	1.18	14.72	41.23	15.90	42.41
Oil	8.94	28.91	83.06	37.85	92.00
Renewable energy sources					
Biomass**	8.08	7.45	16.48	15.54	24.56
Photovoltaics	0.82	1.90	5.36	2.72	6.18
Hydropower	0.08	0.13	0.36	0.21	0.43
Wind energy***	0.37	0.56	1.58	0.93	1.95

Please note that the value factors in this table represent approximate rather than exact figures, showing the order of magnitude of the environmental impacts. However, since the valuation of environmental impacts in the energy sector tends to involve larger quantities, e.g. millions of kilowatt-hours generated, we have decided to round no further than to two decimal places to avoid an excessive accumulation of rounding errors.

* Based on AG Energiebilanzen e.V. (2025).
** Average value weighted by generation shares for gaseous, liquid and solid biomass.
*** Average value from onshore and offshore wind energy weighted according to generation shares.
Source: Own representation based on Walther et al. (2024b), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

4.2 Value Factors for Heat Generation

The general approach for assessing the monetized environmental impacts of heat generation is the same as for electric power generation: Emission factors from the German Environment Agency are used to assess the direct and indirect GHG and air pollutant emissions from heat generation for different energy sources. These emission factors are then weighted with the value factors for GHG and air pollutant emissions from Chapters 2 and 3 to arrive at monetized environmental impacts for heat generation.

Similar to electric power generation, we follow a generic, national-level approach. If a site-specific assessment is required, the differentiated value factors from Chapter 3 should be used. Please see Section 4.4 for further methodological background. Two value factors are provided for each energy source – one using a 0% Pure Rate of Time Preference (PRTP) and one using a 1% PRTP for GHG emissions (see Section 2.2 for further information).

Table 6: Value factors for heat generation of households in Germany in €-cent$_{2025}$ / kWh$_{final\ energy}$

Value factors for heat generation in €-cent$_{2025}$/kWh$_{final\ energy}$					
Heat generation from	**Air pollutants**	**Greenhouse gases (1% PRTP)**	**Greenhouse gases (0% PRTP)**	**Total environmental impacts (1% PRTP)**	**Total environmental impacts (0% PRTP)**
Fossil energy sources					
Heating oil	1.51	10.73	30.88	12.24	32.39
Natural gas	0.65	8.07	22.69	8.72	23.34
Lignite (briquette)	12.17	15.04	42.55	27.21	54.72
District heating with grid losses*	1.78	9.82	27.62	11.60	29.40
Electricity heating with grid losses**	2.85	16.42	46.60	19.26	49.45
Renewable energy sources					
Solar thermal	0.45	0.75	2.12	1.20	2.57
Surface geothermal energy and ambient heat	1.31	5.50	15.60	6.81	16.91
Deep geothermal energy	0.28	1.18	3.36	1.47	3.64
Biomass***	4.01	1.20	2.83	5.22	6.85

Please note that the value factors in this table represent approximate rather than exact figures, showing the order of magnitude of the environmental impacts. However, since the valuation of environmental impacts in the energy sector tends to involve larger quantities, like millions of kilowatt-hours generated, we have decided to round no further than to two decimal places to avoid an excessive accumulation of rounding errors.

* The value factors vary, in some cases considerably, depending on the heat source.
** This is based on the average rate for power generation (incl. renewable energy sources and taking into account the upstream value chains for the generation of the respective fuels.
*** Average value for gaseous, liquid and solid biomass weighted by production shares.
Source: Own representation based on Walther et al. (2024b), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

4.3 Environmental Impacts of Refrigeration and Cooling

In contrast to heat generation, which has seen a decrease in overall energy consumption in recent years due to the use of more efficient and environmentally friendly technologies, cooling and refrigeration show an opposite trend. The demand for air conditioning is increasing due to rising temperatures, especially in urban areas. Furthermore, a significant increase in data centers, which require substantial cooling, is contributing to this trend. Despite advancements in refrigeration and cooling technologies, efficiency improvements are not enough to balance the growing demand. Besides the increasing energy consumption and associated environmental impacts, refrigeration and cooling cause environmental damages through the release of refrigerants. In particular, hydrofluorocarbons (HFCs), whose use as refrigerants is still increasing globally, tend to have high atmospheric lifetimes and Global Warming Potentials exceeding that of CO_2 by several orders of magnitude (UBA 2025a, 2025b).

Over 80% of the overall cooling energy is used in the cooling of processes (industrial processes, data centers, refrigeration) while the remaining close to 20% are used for air conditioning. Around 98% of the energy used for cooling is based on electric power, the remaining 2% on oil and gas.

At present it is not possible to recommend value factors for cooling and refrigeration systems. This section focusses on the specific challenges of deriving value factors for cooling and refrigeration and presents value factors for different refrigerants as a starting point. A description of the methodological approach followed by Walther et al. (2024b), on whose work this chapter is based, can be found in Section 4.4.

The efficiency of refrigeration devices and systems is heavily dependent on the overall design and varies depending on the technology and refrigerant used for the refrigeration process[20]. This is particularly true for industrial applications as the use of heat exchangers makes it difficult to attribute the energy input as well as the associated environmental impacts to one specific process or device: Waste heat recovery has a positive effect on the overall energy balance as it can be used for hot water or heat generation in general, thereby leading to lower energy consumption in these areas. However, waste heat recovery is not considered for determining the standardised efficiency ratios of refrigeration systems and is highly dependent on the specific design and set up of the underlying system. Therefore, it is difficult to arrive at general conclusions with respect to the environmental performance of specific refrigeration systems.

Due to the poor data availability, in combination with the fact that the environmental impacts vary widely depending on the energy consumption, the energy source's environmental intensity, the refrigerant's GWP100 as well as the yearly refrigerant losses and recovery rates, it is not possible at this time to arrive at meaningful average value factors for different types of cooling and refrigeration systems and devices.

However, the GHG and air pollutant emission related impacts of a specific cooling or refrigeration device can instead be assessed by using information regarding the energy consumption as well as the refrigerant and system specific characteristics – as far as these are available. Table 7 below provides an overview of the most frequently used refrigerants of household as well as industrial and commercial applications and their respective Global Warming Potential as GWP100 values. All listed refrigerants have zero ozone depletion potential. Based on the GWP100 values as well as the value factors for CO_2-emissions from Chapter 2, we calculate value factors per kg of refrigerant loss.

The value factors in Table 5 in Section 4.1 can be used for assessing the energy consumption of refrigeration and cooling systems. To assess the monetized environmental impacts related to GHG and air pollutant emissions of a specific cooling system, one would thus combine data on the net energy consumption attributable to the cooling system and refrigerant losses with the value factors in Table 5 and Table 7.

[20] Vapor compression refrigeration is the most commonly used technology for air conditioning as well as refrigerators and industrial processes. This technology relies on the use of refrigerants which are often associated with high Global Warming Potential (GWP100) values. Other technologies used for these applications include adsorption and absorption refrigeration units.

Table 7: GWP100 values and value factors for commonly used refrigerants

Classification	Category	Refrigerant	GWP100	Value factor €2025/ kg of refrigerant (1% PRTP)	Value factor €2025/ kg of refrigerant (0% PRTP)
Refrigerants stable in the air	Hydrofluoro-carbons	R-32	**675**	230	670
		R-134a	**1,430**	490	1,415
		R-410A	**2,088**	720	2,070
Refrigerants non stable in the air	Propane	R-290	**3**	1	3
	NH_3	R-717	**0**	0	0
	CO_2	R-744	**1**	0.3	1
	Isobutane	R-600a	**3**	1	3
	Propane	R-1270	**2**	0.7	2

Source: Own representation based on Walther et al. (2024b).

4.4 Methodological Background

4.4.1 Electric Power and Heating

As briefly explained in Sections 4.1 and 4.2, the value factors for electric power and heat generation are based on emission factors published by the German Environment Agency (UBA 2022b) and the value factors for GHG and air pollutant emissions from Chapters 2 and 3.

The emission factors indicate how many grams of a respective pollutant are emitted per kilowatt-hour of electric power or heat generated (i.e. g/kWh_{el} for electric power and $g/kwh_{final\ energy}$ for heat generation) and differentiate between direct and indirect emissions. Direct emissions refer to emissions that arise in the immediate context of power generation, i.e. during the operational phase of energy generation with different technologies, such as the actual process of combusting coal. Indirect emissions arise during the up- and downstream phases of the life cycle, e.g., construction, maintenance and decommissioning of power plants. The emission factors used to compute the value factors in this chapter consider indirect emissions relating to the supply chain as well as auxiliary energies. However, they do not incorporate downstream phases.

By multiplying the emission factors with the value factors presented in Chapters 2 and 3, it is possible to compute the monetized environmental impacts of power generation related to GHG and air pollutant emissions (in €-cent/kWh). Through comparison of the resulting value factors per kWh, it is possible, inter alia, to assess the environmental impacts avoided by generating power from renewable sources instead of using fossil fuels. However, it should be borne in mind that the value factors only factor in greenhouse gases and air pollutants. Other environmental impacts, such as impacts on ecosystems or land use change, are not accounted for in the value factors.

When trying to derive value factors for power and heat generation, two different approaches can be chosen: If the aim is to have a source-specific analysis, information and assumptions on the locations of the power or heat generation facilities as well as their specific GHG and air pollutant emissions are required. For such cases, where individual, site-specific environmental impacts are to be assessed, we recommend using the differentiated value factors from Chapter 3 for valuing air pollutants. For an analysis at the national level, information on overall emissions in Germany is sufficient. Such more generic calculations are easier to perform and to update once new emission factors become available, since only national averages rather than individual source parameters need to be adjusted. Site-specific analyses tend to deviate from the average in particular for sources with very high or very low emissions. For those an individual analysis may be warranted. For the purposes of this handbook, however, we focus on the average impacts of electricity and heat generation. Accordingly, the value factors in this chapter are based on overall emissions. For the assessment of air pollutants this implies that the generic value factors were used for direct and indirect emissions.

4.4.2 Cooling and Refrigeration

The use of cooling technology can be divided into four broad application areas: industry, households, transportation and the tertiary sector (trade, commerce and services). For this chapter, the transportation sector was not considered. Within the remaining three areas of application, a general distinction can be made between cooling energy for air conditioning and for refrigeration.

The efficiency of refrigeration units is typically indicated by the energy efficiency ratio (EER) or the seasonal energy efficiency ratio (SEER) in the case of air conditioning. These ratios specify the relation between refrigeration performance and electric power input under standardised exterior and interior temperature settings. In order to arrive at GHG and air pollutant emission related value factors for refrigeration and cooling, similar to those for heating, Walther et al. (2024b) took the efficiency ratios of common refrigeration systems as well as the mix of energy sources and emission factors for air pollutants and GHG to arrive at the emissions per unit of cooling energy (g/kWh). Walther et al. (2024b) focused on the operational phase of cooling and refrigeration systems, i.e. emissions from energy use in other life cycle phases were not considered. This was due to poor data availability but also because according to expert opinions, the energy used in other life cycle phases is negligible compared to the use phase (Lang and Werner 2022).

For GHG, it is furthermore necessary to consider the GHG emissions related to the refrigerant used. The approach pursued by Walther et al. (2024b) is partly based on the concept of total equivalent warming impact (TEWI), a standardized calculation methodology that maps the refrigerant losses and emissions caused by the energy supply for the operation of a system over its entire life cycle. However, as stated above, in Walther et al. (2024b) the energy supply is only considered for the operational phase. For refrigerant losses, the use and disposal phase are considered, as most refrigerant losses occur in the disposal phase. Refrigerant losses are specified for the various system types in the unit '% of charge per year'. The amount of refrigerant loss (in g) can be calculated from the refrigerant charge (in g), the leakage rate during use (in %/a), the average service life and the losses during disposal. The annual losses (in g/a) and the annual cooling energy (in kWh) can be used to estimate the specific losses in (g/kWh). Emissions of CO_2 equivalents in grams per kilowatt hour can be determined from the GWP100 values of the refrigerants and the refrigerant losses per kilowatt hour of cooling energy.

As explained above, it is not possible at present to derive robust average value factors for refrigeration or air conditioning for Germany, due to the strong dependence of the environmental impacts on application-specific parameters, and poor data availability.

However, for specific refrigeration or air conditioning devices, the total greenhouse gas emissions (energy provision and refrigerant losses, where applicable) would be multiplied by the GHG value factors, while the air pollutant emissions would be multiplied by the respective value factors. Together, this would then yield specific value factors for refrigeration or air conditioning per kWh for the respective device or technology, when energy consumption and refrigerant loss are known.

5 Passenger and Freight Transport in Germany

Both, passenger and freight transport have significant direct and indirect environmental impacts, e.g. through the emission of greenhouse gases and air pollutants (exhaust and abrasion). In addition, transport causes noise as well as adverse impacts on nature and landscape, primarily due to landscape fragmentation and land sealing by the required infrastructure. The results and value factors in this chapter are based on the work by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) as well as own calculations. Due to lack of data, they do not include effects of noise and impacts on ecosystems and landscape.

5.1 Value Factors for Transport-Related Activities

Value factors for transport-related activities are presented for different road types and surroundings, that is, an average of transport on all routes, urban areas, rural areas and motorways. The breakdown of mileage in different surroundings in Table 8 is taken from TREMOD (Transport Emission Model) used by the German Environment Agency.

Table 8: Breakdown of mileage in road transport (urban, rural, motorway) by vehicle category, average 2021-2023

Vehicle type	Urban	Rural	Motorway
Cars	26%	44%	30%
Light commercial vehicles (LCV)	36%	37%	27%
Heavy goods vehicles (HGV)	14%	28%	59%
Motorcycles	47%	44%	9%
Public buses	31%	62%	7%
Coaches	23%	36%	41%

Source: HBEFA 4.2 and TREMOD 6.61c.

The value factors for transport-related activities illustrated in Table 9 through Table 16[21] are computed by linking emission factors for the various vehicle categories and life cycle phases with the value factors for greenhouse gas and air pollutant emissions in Chapters 2 and 3. They are shown for GHG value factors based on 1% and 0% PRTP (see Chapter 2). The asterisks (***) in the column for noise indicate that traffic noise has significant impacts on the environment as well as human health and well-being, but these impacts cannot be broken down by vehicle, person or tonne kilometers based on currently available data (details see Section 5.2).

[21] Please note that the value factors in these tables represent approximate rather than exact figures, showing the order of magnitude of the environmental impacts. However, since the valuation of environmental impacts in the transport sector tends to involve larger quantities, e.g. millions of kilometers driven, we have decided to round no further than to two decimal places to avoid an excessive accumulation of rounding errors.

Table 9: a) Value factors per vehicle kilometer (average of all routes) for different vehicle types in Germany, 0% PRTP for GHG value factors, €-cent$_{2025}$ /vehicle km

Value factors in €-cent$_{2025}$ / vehicle km, average of all routes, 0% PRTP								
Vehicle category	Specification	Operation			Noise	Pre-processes		Total (0% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion		Infra-structure and vehicles	Energy supply	
Car	Petrol	16.09	0.46	0.20	***	8.00	6.15	30.91
Car	Diesel	17.48	2.40	0.20	***	8.20	4.90	33.18
Car	Electric*	0.00	0.00	0.20	***	12.35	9.24	21.79
Small motorcycle	Diesel	6.21	3.16	0.07	***	3.49	2.44	15.38
Motorcycle	Petrol	12.38	0.71	0.07	***	5.31	4.36	22.83
LCV	Diesel	24.40	3.39	0.20	***	9.16	7.44	44.59
LCV	Petrol	18.46	0.77	0.20	***	9.16	7.06	35.65
LCV	Electric	0.00	0.00	0.20	***	14.15	12.05	26.40
HGV <7.5t	Diesel	37.07	5.69	1.08	***	9.16	7.44	60.43
HGV 7.5-14t	Diesel	41.90	5.52	1.08	***	12.37	9.96	70.83
HGV 14-28t	Diesel	62.87	6.81	1.08	***	32.49	22.37	125.61
HGV 28-40t	Diesel	82.83	4.78	1.08	***	54.50	24.90	168.09
Public bus	Diesel	97.65	14.57	2.05	***	26.22	33.25	173.74
Coach	Diesel	68.82	9.39	1.24	***	26.01	22.39	127.84
Passenger train, long distance	Electric	0.00	0.00	6.24	***	175.32	827.05	1008.60
Passenger train, local transport	Weighted av.	52.69	20.71	3.15	***	48.36	338.80	463.72
Freight train	Weighted av.	110.16	50.77	7.38	***	329.67	849.85	1347.83
Passenger air transport	Short and medium haul	1844.76	223.29	-	***	31.32	271.64	2371.02
Passenger air transport	Long haul	3753.59	357.33	-	***	30.23	405.43	4546.58

Value factors in €-cent$_{2025}$ / vehicle km, average of all routes, 0% PRTP								
Vehicle category	Specification	Operation			Noise	Pre-processes		Total (0% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion		Infra-structure and vehicles	Energy supply	
Freight air transport	**Weighted av.**	4942.15	531.21	-	***	48.49	555.03	6076.89
Inland dry cargo motor vessel	**National**	1981.45	1223.09	-	***	766.18	567.59	4538.32
Inland tank motor vessel	**National**	2892.37	1772.09	-	***	795.86	828.53	6288.85
Inland pushed convoy	**National**	4416.48	2715.51	-	***	766.18	706.14	8604.31

LCV = Light Commercial Vehicle; HGV = Heavy Goods Vehicle
Weighted Av. = Weighted Average.
The value factors for air transport proportionally account for belly freight.
*Please note that 2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles, which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020). If we assumed that the overall GHG emissions from electricity generation (i.e related to the electricity mix but also the emissions from the construction and operation of the power plants) would e.g. decrease by 80% as compared to 2022, the overall value factors for BEV assuming a 0% PRTP would drop to 15.19 €-cent.
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Table 10: b) Value factors per vehicle kilometer (average of all routes) for different vehicle types in Germany, 1% PRTP for GHG value factors, €-cent2025 / vehicle km

Value factors in €-cent2025 / vehicle km, average of all routes, 1% PRTP								
Vehicle category	Specification	Operation			Noise	Pre-processes		Total (1% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion		Infra-structure and vehicles	Energy supply	
Car	**Petrol**	5.58	0.46	0.20	***	3.55	2.71	12.50
Car	**Diesel**	6.08	2.40	0.20	***	3.64	2.10	14.43
Car	**Electric***	0.00	0.00	0.20	***	6.34	3.85	10.39
Small motorcycle	**Diesel**	2.27	3.16	0.07	***	1.59	1.05	8.15
Motorcycle	**Petrol**	4.31	0.71	0.07	***	2.48	1.87	9.44
LCV	**Diesel**	8.48	3.39	0.20	***	4.16	3.19	19.42
LCV	**Petrol**	6.40	0.77	0.20	***	4.16	3.10	14.64
LCV	**Electric**	0.00	0.00	0.20	***	7.61	5.02	12.84
HGV <7.5t	**Diesel**	12.88	5.69	1.08	***	4.16	3.19	27.00
HGV 7.5-14t	**Diesel**	14.56	5.52	1.08	***	5.64	4.27	31.07
HGV 14-28t	**Diesel**	21.86	6.81	1.08	***	14.93	9.60	54.27
HGV 28-40t	**Diesel**	28.82	4.78	1.08	***	24.80	10.69	70.17
Public bus	**Diesel**	33.92	14.57	2.05	***	11.25	14.09	75.88
Coach	**Diesel**	23.92	9.39	1.24	***	11.61	9.61	55.77
Passenger train, long distance	**Electric**	0.00	0.00	6.24	***	79.01	322.46	407.72
Passenger train, local transport	**Weighted av.**	18.28	20.71	3.15	***	21.80	133.89	197.83
Freight train	**Weighted av.**	38.22	50.77	7.38	***	148.26	334.87	579.50
Passenger air transport	**Short and medium haul**	640.11	223.29	-	***	12.06	122.56	998.02
Passenger air transport	**Long haul**	1302.00	357.33	-	***	11.64	182.93	1853.90

Value factors in €-cent$_{2025}$ / vehicle km, average of all routes, 1% PRTP								
Vehicle category	Specification	Operation			Noise	Pre-processes		Total (1% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion		Infra-structure and vehicles	Energy supply	
Freight air transport	**Weighted av.**	1714.33	531.21	-	***	18.67	250.56	2514.77
Inland dry cargo motor vessel	**National**	687.37	1223.09	-	***	331.61	273.58	2515.65
Inland tank motor vessel	**National**	1003.37	1772.09	-	***	355.50	399.35	3530.30
Inland pushed convoy	**National**	1532.09	2715.51	-	***	331.61	335.27	4914.49

LCV = Light Commercial Vehicle; HGV = Heavy Goods Vehicle
Weighted Av. = Weighted Average.
The value factors for air transport proportionally account for belly freight.
*Please note that 2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles, which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020).
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Table 11: a) Value factors per vehicle kilometer (motorway) for different vehicle types in Germany, 0% PRTP for GHG value factors, in €-cent$_{2025}$ / vehicle km

Value factors in €-cent$_{2025}$ / vehicle km, motorway, 0% PRTP								
Vehicle category	Specification	Operation				Pre-processes		Total (0% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infra-structure and vehicles	Energy supply	
Car	**Petrol**	17.00	0.55	0.14	***	8.00	6.15	31.84
Car	**Diesel**	18.42	3.06	0.14	***	8.20	4.90	34.71
Car	**Electric***	0.00	0.00	0.14	***	12.35	9.24	21.72
Small motorcycle	**Diesel**	6.17	2.31	0.03	***	3.49	2.44	14.44
Motorcycle	**Petrol**	12.87	0.87	0.03	***	5.31	4.36	23.43
LCV	**Diesel**	29.27	4.81	0.14	***	9.16	7.44	50.81
LCV	**Petrol**	21.88	0.83	0.14	***	9.16	7.06	39.06
LCV	**Electric**	0.00	0.00	0.14	***	14.15	12.05	26.34
HGV <7.5t	**Diesel**	37.91	5.31	0.60	***	9.16	7.44	60.41
HGV 7.5-14t	**Diesel**	41.61	5.06	0.60	***	12.37	9.96	69.60
HGV 14-28t	**Diesel**	59.45	5.93	0.60	***	32.49	22.37	120.84
HGV 28-40t	**Diesel**	76.68	4.05	0.60	***	54.50	24.90	160.73
Public bus	**Diesel**	71.98	11.92	0.60	***	26.22	33.25	143.96
Coach	**Diesel**	62.25	7.08	0.60	***	26.01	22.39	118.33

LCV = Light Commercial Vehicle; HGV = Heavy Goods Vehicle
*Please note that 2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles, which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020).
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Table 12: b) Value factors per vehicle kilometer (motorway) for different vehicle types in Germany, 1% PRTP for GHG value factors, in €-cent$_{2025}$ / vehicle km

Value factors in €-cent$_{2025}$ / vehicle km, motorway, 1% PRTP								
Vehicle category	Specification	Operation				Pre-processes		Total (1% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infra-structure and vehicles	Energy supply	
Car	**Petrol**	5.90	0.55	0.14	***	3.55	2.71	12.83
Car	**Diesel**	6.40	3.06	0.14	***	3.64	2.10	15.34
Car	**Electric***	0.00	0.00	0.14	***	6.34	3.85	10.32
Small motorcycle	**Diesel**	2.24	2.31	0.03	***	1.59	1.05	7.23
Motorcycle	**Petrol**	4.47	0.87	0.03	***	2.48	1.87	9.73
LCV	**Diesel**	10.16	4.81	0.14	***	4.16	3.19	22.46
LCV	**Petrol**	7.59	0.83	0.14	***	4.16	3.10	15.82
LCV	**Electric**	0.00	0.00	0.14	***	7.61	5.02	12.77
HGV <7.5t	**Diesel**	13.17	5.31	0.60	***	4.16	3.19	26.42
HGV 7.5-14t	**Diesel**	14.46	5.06	0.60	***	5.64	4.27	30.03
HGV 14-28t	**Diesel**	20.67	5.93	0.60	***	14.93	9.60	51.73
HGV 28-40t	**Diesel**	26.68	4.05	0.60	***	24.80	10.69	66.82
Public bus	**Diesel**	25.02	11.92	0.60	***	11.25	14.09	62.87
Coach	**Diesel**	21.64	7.08	0.60	***	11.61	9.61	50.54

LCV = Light Commercial Vehicle; HGV = Heavy Goods Vehicle
*Please note that 2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles, which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020).
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Table 13: a) Value factors per vehicle kilometer (rural) for different vehicle types in Germany, 0% PRTP for GHG value factors, in €-cent$_{2025}$ / vehicle km

Value factors in €-cent$_{2025}$ / vehicle km, rural, 0% PRTP								
Vehicle category	Specification	Operation				Pre-processes		Total (0% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infra-structure and vehicles	Energy supply	
Car	**Petrol**	14.47	0.40	0.14	***	8.00	6.15	29.17
Car	**Diesel**	16.18	2.05	0.14	***	8.20	4.90	31.47
Car	**Electric***	0.00	0.00	0.14	***	12.35	9.24	21.72
Small motorcycle	**Diesel**	6.21	2.38	0.04	***	3.49	2.44	14.56
Motorcycle	**Petrol**	11.32	0.71	0.04	***	5.31	4.36	21.74
LCV	**Diesel**	22.58	3.01	0.14	***	9.16	7.44	42.32
LCV	**Petrol**	16.90	0.70	0.14	***	9.16	7.06	33.95
LCV	**Electric**	0.00	0.00	0.14	***	14.15	12.05	26.34
HGV <7.5t	**Diesel**	36.70	5.50	0.77	***	9.16	7.44	59.56
HGV 7.5-14t	**Diesel**	42.81	5.37	0.77	***	12.37	9.96	71.27
HGV 14-28t	**Diesel**	66.57	6.72	0.77	***	32.49	22.37	128.91
HGV 28-40t	**Diesel**	89.62	4.82	0.77	***	54.50	24.90	174.61
Public bus	**Diesel**	95.41	12.83	1.01	***	26.22	33.25	168.72
Coach	**Diesel**	71.18	8.97	0.87	***	26.01	22.39	129.42
Passenger train, long distance	**Electric**	0.00	0.00	6.24	***	175.32	827.05	1008.60
Passenger train, local transport	**Weighted av.**	52.69	20.41	3.15	***	48.36	338.80	463.43
Freight train	**Weighted av.**	110.16	49.80	7.38	***	329.67	849.85	1346.87

LCV = Light Commercial Vehicle; HGV = Heavy Goods Vehicle
Weighted Av. = Weighted Average electric/diesel.
*Please note that 2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles, which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020).
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Table 14: b) Value factors per vehicle kilometer (rural) for different vehicle types in Germany, 1% PRTP for GHG value factors, in €-cent$_{2025}$ / vehicle km

Value factors in €-cent$_{2025}$ / vehicle km, rural, 1% PRTP								
Vehicle category	**Specification**	**Operation**				**Pre-processes**		**Total (1% PRTP)**
		Green-house gases	**Air pollutants Exhaust**	**Air pollutants Abrasion**	**Noise**	**Infra-structure and vehicles**	**Energy supply**	
Car	**Petrol**	5.02	0.40	0.14	***	3.55	2.71	11.81
Car	**Diesel**	5.63	2.05	0.14	***	3.64	2.10	13.56
Car	**Electric***	0.00	0.00	0.14	***	6.34	3.85	10.32
Small motorcycle	**Diesel**	2.27	2.38	0.04	***	1.59	1.05	7.33
Motorcycle	**Petrol**	3.94	0.71	0.04	***	2.48	1.87	9.04
LCV	**Diesel**	7.85	3.01	0.14	***	4.16	3.19	18.35
LCV	**Petrol**	5.86	0.70	0.14	***	4.16	3.10	13.96
LCV	**Electric**	0.00	0.00	0.14	***	7.61	5.02	12.77
HGV <7.5t	**Diesel**	12.75	5.50	0.77	***	4.16	3.19	26.37
HGV 7.5-14t	**Diesel**	14.87	5.37	0.77	***	5.64	4.27	30.92
HGV 14-28t	**Diesel**	23.14	6.72	0.77	***	14.93	9.60	55.16
HGV 28-40t	**Diesel**	31.18	4.82	0.77	***	24.80	10.69	72.25
Public bus	**Diesel**	33.15	12.83	1.01	***	11.25	14.09	72.33
Coach	**Diesel**	24.74	8.97	0.87	***	11.61	9.61	55.80
Passenger train, long distance	**Electric**	0.00	0.00	6.24	***	79.01	322.46	407.72
Passenger train, local transport	**Weighted av.**	18.28	20.41	3.15	***	21.80	133.89	197.53
Freight train	**Weighted av.**	38.22	49.80	7.38	***	148.26	334.87	578.53

LCV = Light Commercial Vehicle; HGV = Heavy Goods Vehicle
Weighted Av. = Weighted Average electric/diesel.
*Please note that 2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles, which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020).
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Table 15: a) Value factors per vehicle kilometer (urban) for different vehicle types in Germany, 0% PRTP for GHG value factors, in €-cent$_{2025}$ / vehicle km

Value factors in €-cent$_{2025}$ / vehicle km, urban, 0% PRTP								
Vehicle category	Specification	Operation				Pre-processes		Total (0% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infra-structure and vehicles	Energy supply	
Car	**Petrol**	16.90	0.47	0.85	***	8.00	6.15	32.38
Car	**Diesel**	17.98	2.26	0.85	***	8.20	4.90	34.19
Car	**Electric***	0.00	0.00	0.85	***	12.35	9.24	22.44
Small motorcycle	**Diesel**	6.21	10.88	0.33	***	3.49	2.44	23.35
Motorcycle	**Petrol**	12.90	1.15	0.33	***	5.31	4.36	24.05
LCV	**Diesel**	22.31	3.02	0.85	***	9.16	7.44	42.78
LCV	**Petrol**	17.20	0.81	0.85	***	9.16	7.06	35.08
LCV	**Electric**	0.00	0.00	0.85	***	14.15	12.05	27.05
HGV <7.5t	**Diesel**	33.73	8.14	7.86	***	9.16	7.44	66.32
HGV 7.5-14t	**Diesel**	40.50	7.79	7.86	***	12.37	9.96	78.47
HGV 14-28t	**Diesel**	68.28	10.62	7.86	***	32.49	22.37	141.61
HGV 28-40t	**Diesel**	92.80	8.03	7.86	***	54.50	24.90	188.10
Public bus	**Diesel**	104.28	17.16	11.10	***	26.22	33.25	192.01
Coach	**Diesel**	76.81	14.34	8.22	***	26.01	22.39	147.76
Passenger train, long distance	**Electric**	0.00	0.00	6.24	***	175.32	827.05	1008.60
Passenger train, local transport	**Weighted av.**	52.69	23.58	3.15	***	48.36	338.80	466.59
Freight train	**Weighted av.**	110.16	60.21	7.38	***	329.67	849.85	1357.28

LCV = Light Commercial Vehicle; HGV = Heavy Goods Vehicle
Weighted Av. = Weighted Average electric/diesel.
*Please note that 2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles, which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020).
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Table 16: b) Value factors per vehicle kilometer (urban) for different vehicle types in Germany, 1% PRTP for GHG value factors, in €-cent2025 / vehicle km

Value factors in €-cent2025 / vehicle km, urban, 1% PRTP								
Vehicle category	Specification	Operation				Pre-processes		Total (1% PRTP)
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infra-structure and vehicles	Energy supply	
Car	Petrol	5.86	0.47	0.85	***	3.55	2.71	13.44
Car	Diesel	6.26	2.26	0.85	***	3.64	2.10	15.11
Car	Electric*	0.00	0.00	0.85	***	6.34	3.85	11.04
Small motorcycle	Diesel	2.27	10.88	0.33	***	1.59	1.05	16.12
Motorcycle	Petrol	4.49	1.15	0.33	***	2.48	1.87	10.32
LCV	Diesel	7.76	3.02	0.85	***	4.16	3.19	18.98
LCV	Petrol	5.97	0.81	0.85	***	4.16	3.10	14.89
LCV	Electric	0.00	0.00	0.85	***	7.61	5.02	13.49
HGV <7.5t	Diesel	11.73	8.14	7.86	***	4.16	3.19	35.07
HGV 7.5-14t	Diesel	14.08	7.79	7.86	***	5.64	4.27	39.63
HGV 14-28t	Diesel	23.74	10.62	7.86	***	14.93	9.60	66.74
HGV 28-40t	Diesel	32.29	8.03	7.86	***	24.80	10.69	83.67
Public bus	Diesel	36.22	17.16	11.10	***	11.25	14.09	89.82
Coach	Diesel	26.70	14.34	8.22	***	11.61	9.61	70.47
Passenger train, long distance	Electric	0.00	0.00	6.24	***	79.01	322.46	407.72
Passenger train, local transport	Weighted av.	18.28	23.58	3.15	***	21.80	133.89	200.70
Freight train	Weighted av.	38.22	60.21	7.38	***	148.26	334.87	588.94

LCV = Light Commercial Vehicle; HGV = Heavy Goods Vehicle
Weighted Av. = Weighted Average electric/diesel.
*Please note that 2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles, which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020).
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Detailed data on value factors per vehicle kilometer for the different Euronorm classes can be found in the appendix.

To enable a conversion of value factors per vehicle kilometer for the different vehicle types into value factors per passenger kilometer (Pkm) and tonne kilometer (tkm), information on the rate of occupation/utilization by vehicle type is needed. For this purpose, data for the year 2022 from the market investigation of the German Network Agency (Bundesnetzagentur 2024) on utilization rates were used for trains and recommendations from TREMOD 6.51 were used for all other vehicles. This information is summarized in Table 17 below.

Table 17: Rate of occupation/utilization by vehicle type

Vehicle category	Passengers / vehicle	Tonnes / vehicle
Car	1.40	
Small motorcycle	1.00	
Motorcycle	1.40	
Public bus	12.90	
Coach	24.90	
Passenger train, long distance	261	
Passenger train, local transport	72	
Passenger air transport (short- and medium haul)	124	
Passenger air transport (long haul)	199	
Light commercial vehicles (LCV)		0.40
Heavy goods vehicles (HGV) <7.5t		0.92
HGV 7.4-14t		1.59
HGV 14-28t		3.39
HGV: Trailer 28-40t		10.03
Freight train		560
Freight air transport		52.82
Inland waterways transport motor vessels		938
Inland waterways transport water craft assemblies		1,902

No utilization data is available for light commercial vehicles (LCV).
Source: TREMOD 6.51 and Bundesnetzagentur (2024).

With these occupation / utilization rates, all value factors indicated as €-cent per vehicle kilometer can be converted into €-cent per passenger kilometer (Pkm) or tonne kilometer (tkm).

Table 18 exemplarily illustrates the resulting average value factors (across all routes, emission factors for 2022) per passenger or tonne kilometer.

Table 18: Value factors per passenger (Pkm) or tonne (tkm) kilometer for various vehicle types in Germany in €-cent$_{2025}$ / Pkm or tkm

Vehicle type	Specification	Unit	Total environmental costs (GHG value factors with 1% PRTP)	Total environmental costs (GHG value factors with 0% PRTP)
Car	**Petrol**	€-Cent/Pkm	8.93	22.09
Car	**Diesel**	€-Cent/Pkm	10.31	23.72
Car	**Electric**	€-Cent/Pkm	7.43	15.57
Small motorcycle	**Diesel**	€-Cent/Pkm	8.57	16.19
Motorcycle	**Petrol**	€-Cent/Pkm	6.74	16.30
Public bus	**Diesel**	€-Cent/Pkm	5.88	13.47
Coach	**Diesel**	€-Cent/Pkm	4.32	9.91
Passenger train, long distance	**Electric**	€-Cent/Pkm	1.56	3.86
Passenger traing, local transport	**Weighted av.**	€-Cent/Pkm	2.75	6.44
Passenger air transport*	**Short and medium haul**	€-Cent/Pkm	7.81	18.55
Passenger air transport*	**Long haul**	€-Cent/Pkm	9.04	22.16
HGV <7.5t	**Diesel**	€-Cent/tkm	29.32	65.62
HGV 7.5-14t	**Diesel**	€-Cent/tkm	19.59	44.66
HGV 14-28t	**Diesel**	€-Cent/tkm	15.99	37.01
HGV 28-40t	**Diesel**	€-Cent/tkm	7.00	16.76
Freight train	**Weighted av.**	€-Cent/tkm	1.03	2.41
Freight air transport	**Weighted av.**	€-Cent/tkm	52.32	127.04
Inland dry cargo motor vessel	**National**	€-Cent/tkm	2.68	4.84
Inland tank motor vessel	**National**	€-Cent/tkm	3.76	6.71
Inland pushed convoy	**National**	€-Cent/tkm	2.58	4.52

Weighted. av. = Weighted average electric/diesel.
The value factors in Table 18 do not account for noise related impacts.
*Value factors for passenger air transport are adjusted for belly freight, i.e. the environmental impacts related to belly freight are not attributed to passenger kilometers.
Source: Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

5.2 Value Factors for Noise

Due to the high population density and traffic volume, broad sections of the German population are affected by noise. People exposed to high levels of noise pollution experience annoyance and adverse impacts on their health, leading to a reduced quality of life. Road, rail and air traffic represent the main sources of noise pollution. Value factors for these sources are discussed in this chapter based on the work by Bieler and Sutter (2022) and own calculations. For the assessment of noise-related effects on human health and well-being, it is particularly important to consider the specific surroundings and circumstances (noise characteristics, distance from the noise source, time of day, population density, etc.).

The monetized health impacts from traffic noise are differentiated according to noise level classes. A distinction is made between road, rail and air traffic in order to properly account for the acoustic properties and the resulting noise effects of these modes of transport.

The value factors provided in Table 19: and Table 20 can, for example, be used to monetize how noise reduction measures lower the impacts of noise pollution. It should be borne in mind, however, that these are average values – for an assessment of noise effects in specific locations or situations, on-site noise measurements are recommended.

Table 19 shows the impacts that people experience in form of the annoyance caused by different noise levels, averaged over day and night. To avoid double counting, the values exclude self-reported sleep-disturbances, a major cause of annoyance.

Table 19: Value factors for impacts of traffic noise related annoyance based on L_{DEN} values (€$_{2025}$/person/year)

	Cost functions by category (€$_{2025}$/person/year)						Total costs (€$_{2025}$/person/year)		
	Intangible costs - YLD			Intangible costs – YLL					
dB(A)	**Road**	**Rail**	**Air**	**Road**	**Rail**	**Air**	**Road**	**Rail**	**Air**
Overall results for annoyance (excluding self-reported sleep disturbances)									
45-49	118	66.45	187	-	-	-	118	66.45	187
50-54	138	123	315	-	-	-	138	123	315
55-59	183	200	447	-	-	-	183	200	447
60-64	253	299	585	-	-	-	253	299	585
65-69	348	418	728	-	-	-	348	418	728
70-74	469	558	877	-	-	-	469	558	877
>= 75	615	720	1,031	-	-	-	615	720	1,031

L_{DEN} = Day-Evening-Night Noise Level; YLD = years lived with disability; YLL = years of life lost;
Source: Bieler and Sutter (2022), own calculations.

Beyond annoyance, noise causes cognitive impairments (measured as learning delays) in children and physical impacts on human health, shown in Table 20. It should be noted that the various categories of physical health impacts cannot be assumed to be statistically independent, which means they cannot be aggregated without further assumptions.

Table 20: Value factors for traffic noise related cognitive impairment in children and impacts on physical and mental health based on L_{DEN} values (€$_{2025}$/person/year)

	Cost functions by category (€$_{2025}$/person/year)						Total costs (€$_{2025}$/person/year)		
	Intangible costs - YLD			Intangible costs – YLL					
dB(A)	Road	Rail	Air	Road	Rail	Air	Road	Rail	Air
Cognitive impairment in children									
45-49	n.d.	n.d.	n.d.	-	-	-	-	-	-
50-54	2.14	2.14	2.14	-	-	-	2.14	2.14	2.14
55-59	13.55	13.55	13.55	-	-	-	13.55	13.55	13.55
60-64	34.08	34.08	34.08	-	-	-	34.08	34.08	34.08
65-69	54.61	54.61	54.61	-	-	-	54.61	54.61	54.61
70-74	75.14	75.14	75.14	-	-	-	75.14	75.14	75.14
>= 75	95.67	95.67	95.67	-	-	-	95.67	95.67	95.67
Ischemic heart disease, all forms									
45-49	n.d.	n.d.	0.65	n.d.	n.d.	0.29	n.d.	n.d.	0.94
50-54	n.d.	n.d.	2.27	n.d.	n.d.	1.01	n.d.	n.d.	3.28
55-59	1.15	0.86	3.89	0.51	0.39	1.73	1.67	1.25	5.62
60-64	2.59	2.30	5.51	1.16	1.03	2.46	3.75	3.33	7.97
65-69	4.03	3.75	7.13	1.80	1.67	3.18	5.83	5.42	10.31
70-74	5.47	5.19	8.75	2.44	2.31	3.90	7.91	7.50	12.65
>= 75	6.91	6.63	10.37	3.08	2.95	4.62	10.00	9.58	15.00
Fatal myocardial infarction									
45-49	n.d.	n.d.	0.25	n.d.	n.d.	1.25	n.d.	n.d.	1.51
50-54	n.d.	n.d.	0.88	n.d.	n.d.	4.39	n.d.	n.d.	5.27
55-59	0.63	0.47	1.51	3.14	2.35	7.52	3.77	2.82	9.04
60-64	1.42	1.26	2.14	7.05	6.27	10.66	8.47	7.53	12.80
65-69	2.21	2.05	2.77	10.97	10.19	13.79	13.18	12.24	16.57
70-74	2.99	2.84	3.40	14.89	14.11	16.93	17.89	16.94	20.33
>= 75	3.78	3.62	4.03	18.81	18.03	20.07	22.59	21.65	24.10
Hypertension									
45-49	n.d.	n.d.	0.11	n.d.	n.d.	0.02	n.d.	n.d.	0.13
50-54	n.d.	n.d.	0.40	n.d.	n.d.	0.07	n.d.	n.d.	0.47
55-59	0.23	0.17	0.69	0.04	0.03	0.12	0.27	0.20	0.81
60-64	0.52	0.46	0.98	0.09	0.08	0.17	0.60	0.54	1.14
65-69	0.80	0.75	1.26	0.14	0.13	0.22	0.94	0.87	1.48
70-74	1.09	1.03	1.55	0.19	0.18	0.26	1.28	1.21	1.81
>= 75	1.38	1.32	1.84	0.24	0.23	0.31	1.61	1.54	2.15
Stroke									
45-49	n.d.	n.d.	1.30	n.d.	n.d.	0.67	n.d.	n.d.	1.97
50-54	n.d.	n.d.	4.56	n.d.	n.d.	2.35	n.d.	n.d.	6.91
55-59	n.d.	n.d.	7.82	n.d.	n.d.	4.02	n.d.	n.d.	11.84
60-64	n.d.	n.d.	11.07	n.d.	n.d.	5.70	n.d.	n.d.	16.77
65-69	n.d.	n.d.	14.33	n.d.	n.d.	7.37	n.d.	n.d.	21.70
70-74	n.d.	n.d.	17.59	n.d.	n.d.	9.05	n.d.	n.d.	26.64
>= 75	n.d.	n.d.	20.84	n.d.	n.d.	10.73	n.d.	n.d.	31.57

dB(A)	Cost functions by category (€2025/person/year) Intangible costs - YLD Road	Rail	Air	Intangible costs – YLL Road	Rail	Air	Total costs (€2025/person/year) Road	Rail	Air
Diabetes mellitus									
45-49	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
50-54	0.19	0.19	0.02	0.35	0.35	0.04	0.55	0.55	0.07
55-59	0.68	0.68	0.08	1.24	1.24	0.15	1.92	1.92	0.24
60-64	1.17	1.17	0.15	2.12	2.12	0.26	3.28	3.28	0.41
65-69	1.65	1.65	0.21	3.00	3.00	0.38	4.65	4.65	0.58
70-74	2.14	2.14	0.27	3.88	3.88	0.49	6.02	6.02	0.75
>= 75	2.62	2.62	0.33	4.77	4.77	0.60	7.39	7.39	0.92
Breast cancer, women									
45-49	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
50-54	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
55-59	0.13	0.13	0.13	0.32	0.32	0.32	0.45	0.45	0.45
60-64	0.45	0.45	0.45	1.12	1.12	1.12	1.57	1.57	1.57
65-69	0.78	0.78	0.78	1.91	1.91	1.91	2.69	2.69	2.69
70-74	1.10	1.10	1.10	2.71	2.71	2.71	3.81	3.81	3.81
>= 75	1.43	1.43	1.43	3.51	3.51	3.51	4.93	4.93	4.93
Unipolar depressive episodes in adults									
45-49	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
50-54	0.24	0.16	n.d.	n.d.	n.d.	n.d.	0.24	0.16	n.d.
55-59	0.49	0.33	n.d.	n.d.	n.d.	n.d.	0.49	0.33	n.d.
60-64	0.73	0.49	0.46	n.d.	n.d.	n.d.	0.73	0.49	0.46
65-69	0.98	0.65	1.60	n.d.	n.d.	n.d.	0.98	0.65	1.60
70-74	1.22	0.81	2.74	n.d.	n.d.	n.d.	1.22	0.81	2.74
>= 75	1.47	0.98	3.88	n.d.	n.d.	n.d.	1.47	0.98	3.88

L_{DEN} = Day-Evening-Night Noise Level; YLD = years lived with disability; YLL = years of life lost;

Source: Bieler and Sutter (2022), own calculations.

Based on the results from noise mapping according to the EU Environmental Noise Directive and the value factors in Table 19 and Table 20 it is possible to derive the overall impacts inflicted on the German population through the cognitive impairment in children and the annoyance caused by traffic noise pollution. The findings of the noise mapping for the year 2022 are illustrated in Table 21. The table shows the number of people that were affected by noise from each mode of transport in the reference year 2022 as well as the monetized impacts from that noise exposure.

The monetized health impacts related to annoyance and cognitive impairment in children in Germany totaled at 5.1 billion €2025 from road traffic noise, 1.1 billion €2025 from rail traffic noise and 415 million €2025 from air traffic noise. Other noise related impacts are not included in these figures and it should be kept in mind that the underlying noise mapping does not cover all potential sources of traffic noise.

Table 21: Traffic noise pollution suffered by the population and resulting impacts from cognitive impairment in children and annoyance (reference year of mapping: 2022)

	L_{DEN} 55-60 dB	L_{DEN} 60-65 dB	L_{DEN} 65-70 dB	L_{DEN} 70-75 dB	L_{DEN} >75 dB
Number of people affected by road traffic noise	7,487,600	4,694,500	3,477,600	1,488,300	133,300
Number of people affected by rail traffic noise	2,005,800	1,128,300	524,900	110,300	17,800
Number of people affected by air traffic noise	723,700	121,800	6,900	700	-
Impacts of road traffic noise related cognitive impairment and annoyance (€$_{2025}$)	1,470,525,400	1,347,890,800	1,401,554,100	809,785,600	94,690,200
Impacts of rail traffic noise related cognitive impairment and annoyance (€$_{2025}$)	428,775,800	375,332,200	248,024,400	69,859,800	14,510,300
Impacts of air traffic noise related cognitive impairment and annoyance (€$_{2025}$)	333,507,800	75,429,200	5,403,000	666,500	-

L_{DEN} = Day-Evening-Night Noise Level

Source: Noise mapping (Lärmkartierung) and own calculations. The EU Environmental Noise Directive tends to lead to an underestimation of the total number of people affected by noise, as the mapping does not cover all sources of traffic noise.

It would be possible to calculate mileage-related value factors for noise (in € per vehicle kilometer, per passenger kilometer or per tonne kilometer) as pure levy quotients: existing noise pollution or the corresponding impacts can be divided by the mileage, e.g. the corresponding vehicle kilometers. As an example, a noise-related toll value factor could be derived, which could then be charged for each kilometer driven. However, such a value factor is ill-suited to monetize the noise effects of random mileage-related measures or developments in the transport sector, because it does not consider differences between noise emissions and exposure. For example, the construction of a bypass road may typically result in an increase in vehicle kilometers while reducing noise exposure, as bypass roads tend to lead through less populated areas. Likewise, an overall decline in annual traffic (in vehicle km) in Germany does not necessarily imply lower levels of noise pollution, as traffic may decrease in sparsely populated areas while increasing in densely populated areas or at night-time, when it is a particular nuisance. For this reason, no mileage-related noise value factors are included in the value factors for transport related activities in Table 9 throughTable 16 in Section 5.1[22]. However, in order to emphasize that traffic-related noise does

[22] In order to e.g. compare variants between two measures or route alternatives, the local, spatial and temporal distribution of the sources, propagation conditions and recipients are to be modelled and the resulting noise exposure is to be calculated for each individual case. This can subsequently be assessed using the relevant exposure-response functions and, if applicable, the exposure-related noise value factors of this handbook.

induce significant environmental and health impacts, the corresponding columns in these tables are marked with asterisks (***).

5.3 Methodological Background

5.3.1 Passenger and Freight Transport

As for power and heat generation, the value factors for transport-related activities are derived by combining emission factors with the value factors for GHG and air pollutant emissions from Chapters 2 and 3.

Emission factors are available for GHG and air pollutant emissions and differentiated by modes of transport (road, air and rail traffic and inland shipping), drive technologies (e.g. internal combustion vs. electric) as well as life cycle phases (direct vs. indirect emissions). Emission factors are provided in grams per vehicle kilometer for the air pollutants NH_3, NMVOC, NO_X, $PM_{2.5}$ and SO_2. Where it was possible, we relied on emission factors differentiated by greenhouse gases, namely CO_2, CH_4 and N_2O, rather than using CO_2-equivalents. For direct emissions, this differentiation could be made for all modes of transport, while for indirect emissions the data was only partially available. The emission factors are mostly based on HBEFA 4.2, TREMOD 6.51 as well as Ecoinvent 3.9 or, more specifically, Mobitool, which is based on the Swiss Federal Office for the Environment's (BAFU) database for environmental assessments.

The value factors for emissions from road and rail transport in Germany are computed for the average fleet composition of the various vehicle types as well as for the Euro standard classes (Euro 1 to Euro 6 for cars and Euro I to Euro VI for trucks[23]) of the vehicle types and their subclasses.

In the aviation sector, for the largest portion of the traveled distance, the combustion process takes place at high altitudes. Combustion processes at high altitudes impact the climate beyond the pure effect of emitting greenhouse gases, in particular by releasing other byproducts of combustion into the atmosphere that are more harmful at high altitudes (UBA 2023a). To reflect this effect, the value factors for the greenhouse gases emitted during flight operations can be multiplied by an emission weighting factor. The applicable emission weighting factor for individual flights depends on a range of parameters, such as the time and location of the emissions and the weather conditions, and can vary substantially. Here, an average emission weighting factor of 3 was used as an approximation (UBA 2025c).

2022 serves as the base year for the emission data. This should be kept in mind, especially with regard to the indirect GHG emission factors for battery electric vehicles (BEV), which are relatively high in comparison to those for petrol and diesel. Given the rapid development in battery technology over the past few years as well as the ongoing shift in the energy mix towards more renewable energies, the indirect emission factors related to GHG emissions for BEV along the value chain are likely to further decrease over the coming years (Thielmann et al. 2020).

As has been discussed in Chapter 3, the severity of air pollutant emission-related health impacts is dependent on the population density, among other things. It follows that the impacts are more pronounced in cities than in rural areas or on motorways. To estimate transport-related value factors (e.g., impacts per vehicle kilometer), it is therefore necessary to assess the air pollutant

[23] In addition to the Euro standard classes 1 to 6 and I to VI, the pollutant emissions for engines used before the introduction of the exhaust emission standard were also considered. In the HBEFA 4.2, these vehicles are indicated as Euro 0 for cars and 80ties for trucks.

emissions in the respective setting and to break down the proportion of mileage in urban areas, rural areas and on motorways.

5.3.2 Noise

To arrive at value factors for traffic noise related impacts, the first step was to identify endpoints relating to the impact categories annoyance and sleep disturbances, physical health as well as cognitive and mental health. In a second step, we identified exposure-response functions (ERF) to assess the effect of traffic noise on the selected endpoints for different noise level classes. Generally, ERF for annoyance and self-reported sleep disturbances are based on surveys, whereas ERF for physical health impacts and cognitive impairment in children are based on observations. For estimating the value factors presented above, the following sources were used:

- For annoyance, we use the World Health Organization's (WHO) exposure-response functions by Guski et al. (2017) and disability weights (DW) from WHO (2024).
- For cognitive impairments in children, we use the ERF in WHO (2011), which links noise levels from air transport to learning delays in children, measured through reading ability scores. Disability weights are taken from the Global Burden of Disease database (IHME (2024), for "mild motor plus cognitive impairments"). These DW are somewhat higher than for mild cognitive impairments in adults in WHO (2024), accounting for the fact that cognitive impairments in children must be expected to have a more intense effect on overall well-being than impairments developed in adults.
- For cardiovascular and metabolic effects (e.g. myocardial infarctions, strokes or diabetes mellitus), we use the exposure-response functions in van Kempen (2018), disability weights are from WHO (2024).
- For breast cancer, we use the exposure-response functions from Seidler et al. (2015) and Sörensen (2014), disability weights are taken from WHO (2024).

The intangible costs for affected population groups can be divided into value factors for years of life lost (YLL) and years lived with disability (YLD). For the YLL value factors, the average years of life lost are multiplied with the Value of a Life Year Lost (VOLY, which is also used in Chapters 2 and 3). For the YLD value factors, on the other hand, the VOLY is weighted by the severity of the impairment (disability weights). The EWB were then combined with the intangible costs to arrive at monetary values for noise-related endpoints, differentiated according to noise level classes and modes of transport.

As can be seen from Table 19 and Table 20, annoyance is the largest driver of the overall noise-related costs for all modes of transport and noise level classes. It is therefore important to note that there is still ongoing discussion in the scientific community with regard to appropriate ERF for annoyance. The approach developed for the WHO by Guski et al. (2017) is well established for estimating the ERF. Nevertheless, it is not undebated from a methodological point of view: the use of a quadratic regression entails that a minimum is reached at a noise level class of 45dB (A) when determining the proportion of highly annoyed persons due to road traffic noise. For lower noise levels, the function exhibits an increase in highly annoyed persons, which is counterintuitive. Fenech et al. (2022) updated the ERF with new studies, while retaining the methodological approach used by Guski et al. (2017). Further research on this issue is required. Until a significantly improved estimate of the ERF becomes available, however, the ERF estimated by Guski et al. (2017) will continue to be used in this handbook.

6 Nitrogen (N) and Phosphorus (P) Emissions

Environmental damages from nitrogen and phosphorus emissions arise along various impact pathways. Nitrogen emissions, among other things, pollute the groundwater and air and thereby entail direct health costs as well as water treatment costs; whereas nitrogen and phosphorus emissions, among other things, impact surface waters through eutrophication and acidification and thus lead to the impairment and loss of ecosystems. The monetized environmental damages that stem from emissions into the air, groundwater as well as surface waters are presented individually below, based on the work by Karzai et al. (2025). When applying the value factors, the relevant impact pathways must be determined for each specific application.

6.1 Emissions into the Air (Direct and Indirect)

For emissions of nitrogen into the air, we recommend using the following value factors when no specific information on the emission source is available (values are consistent with the value factors for N-compounds in the chapter on air pollutants and the value factors for N_2O in the chapter on greenhouse gases).

Table 22: Value factors for nitrogen (N) emissions into the air (direct and indirect, unknown source)

N-compound	Value factor in $€_{2025}$/ kg N
Nitrogen oxides (NO_x)	124
Ammonia (NH_3)	36.82
Nitrous oxide (N_2O), 1% PRTP	186
Nitrous oxide (N_2O), 0% PRTP	444

Source: Karzai et al. (2025), Anthoff (2025), van der Kamp et al. (2024) and own calculations.
Note: In contrast to Chapters 2 and 3, the value factors here refer to 1kg N, not to 1kg of the respective chemical compound (NO_x, NH_3, N_2O); indirect emissions arise, e.g., from the emission of N_2O from soils or from the contribution of NO_x to the formation of particulate matter.

No data regarding the harmful effects of phosphorus emissions into the air are available and consequently no value factors can be specified.

6.2 Emissions into Surface Water and Groundwater

Nitrogen emissions lead to an increase in nitrate (NO_3) concentrations in groundwater. If used as drinking water, this leads to an increase in health risks. Since no recent data is available, we continue to use the study by van Grinsven et al. (2010) on the link between NO_3 in drinking water and the prevalence of colon cancer across several EU countries including Germany.

When determining the damage caused by the emission of nitrogen and phosphorus into surface waters, it should be noted that it is only through the interaction of these two substances that the damaging effect through eutrophication occurs. As plants need a ratio of approximately 16 parts nitrogen to 1 part phosphorus to grow, in almost all cases one of the two substances has a growth-limiting effect. Consequently, the emission of the other substance into the corresponding water body does not cause any additional damage – at least in the short term.

However, exclusively focusing on the limiting substance neglects that in general the concentration of both substances is too high in most water bodies, implying that both substances have a potential for causing damages. The value factors specified below should therefore be interpreted as a **lower bound for damages,** as a value factor of 0 € is applied for the non-limiting substance, thereby ignoring that in most cases the concentration of the non-limiting substance is also above the level that would be appropriate for a good status of the water body[24].

The emission of nitrogen into surface waters also contributes to acidification. However, no damage costs could be determined for this effect.

In the table below, the monetized environmental impacts of N and P are specified assuming that the respective substance is the limiting factor for the eutrophication of the water body in question. Therefore, the entire environmental impact is attributed to the respective substance. When applying the below value factors, it must be determined on a case-by-case basis which substance has a limiting effect. To avoid double counting when ascertaining the total impacts, all of the environmental impacts are to be attributed to this substance.

Table 23: Value factors for nitrogen emissions to groundwater, and of nitrogen and phosphorus as respective growth-limiting factors in surface waters

Substance	Impact pathways	Value factors in $€_{2025}$/ kg
Nitrogen	Groundwater	2.24
	Inland waters	14.08
	Coastal and marine waters	24.86
Phosphorus	Inland waters	437
	Coastal and marine waters	799

Source: Karzai et al. (2025), own calculations.

When nitrogen and phosphorus are emitted into surface waters, the damaging effects first materialize in the inland water bodies and subsequently in the coastal and marine waters (except in the rather rare case of direct emissions to coastal waters). The effects must therefore be added.

In most cases, when assessing phosphorus and nitrogen emissions, it is unknown whether the affected waterbody is limited by phosphorous or nitrogen. For these cases, the following value factors are recommended:

[24] In addition, the ratio of 1:16 is an average value, certain plants may grow under different ratios.

Table 24: Value factors for nitrogen and phosphorus emissions into surface waters when water bodies' limiting substance is unknown

Substance	Value factor in €$_{2025}$/kg
Nitrogen	24.86
Phosphorus	437

Source: Karzai et al. (2025), own calculations.

These average value factors for emissions into surface waters are based on the assumption that the respective pollutant is the sole cause of the damage in the respective type of water body. This reflects that in most inland waters, plant growth is limited by phosphorus, whereas in most marine and coastal waters nitrogen is the limiting substance. Therefore, for the total damage caused by emissions into surface waters (inland waters and sea), the value factor of 24.86 €/kg (value factor for emission into marine waters) should be used for nitrogen, and the value factor of 437 €/kg (value factor for emissions into inland waters) for phosphorus. This way double counting is avoided.

6.3 Methodological Background

Estimating the environmental impacts of nitrogen and phosphorus emissions requires the analysis of several impact pathways. For direct health impacts, this includes the effects of increased nitrate concentrations in drinking water (mostly groundwater), increases in nitrogen oxide (NO_x) concentrations in the air, and the contribution of nitrogen oxide to the formation of particulate matter. In addition, nitrogen and phosphorus emissions impact the quality of surface waters by leading to eutrophication, resulting in reduced ecosystem services (provisioning services such as food production, but also cultural services like recreation or effects on biodiversity). Where surface water is used as drinking water, direct health impacts arise there as well.

Nitrogen emissions also lead to the formation of the greenhouse gas nitrous oxide (N_2O). Finally, nitrogen emissions lead to the acidification of soils. However, due to a general lack of soil-related impact data, this pathway could not be determined for this handbook.

The analysis of direct health impacts is based on background concentrations and the effect of emissions on concentrations for the respective pollutant, and exposure-response functions for the various health impacts (see Chapter 3 for details). For NO_x, only the indirect effects on health through particulate matter formation could be accounted for (see Section 3.4). The impact on climate change is based on the value factors presented in Chapter 2.

For the analysis of eutrophication impacts on surface waters, we account for the biology of plant growth with respect to the availability of nutrients. For this we make use of the Redfield ratio. The Redfield ratio describes the atomic ratio of carbon, nitrogen and phosphorus found in marine phytoplankton and throughout the deep oceans, and is interpreted as describing the limiting factors of plant growth in aquatic ecosystems. In a nutshell, it says that plants in aquatic ecosystems need / can make use of more nitrogen than phosphorus for their growth, with a ratio of approximately 16:1 on average (but considerable variance across plants and studies). Put differently, if either substance limits plant growth in a water body, the effect of 1 kg of phosphorus emitted is far higher than that of 1 kg of nitrogen.

The nutrient that limits plant growth differs between water bodies depending on the atomic ratio between nitrogen and phosphorus in the respective water body being above or below the Redfield ratio. If the impact of nutrient emissions on a particular water body needs to be assessed, therefore, the biochemical conditions for that specific water body should be analyzed. To assess the average impact of emissions, and accounting for the fact that most emissions into watercourses travel long distances and finally end up in coastal waters, more general assumptions on growth-limiting nutrients have to be made. For this, we make use of the fact that in most (though not all) inland waters phosphorus is the limiting factor, while for most coastal and marine waters it is nitrogen. Accordingly, we base the value factors on the simplified assumption that phosphorus emissions cause impacts in all inland waters they travel through, and no impacts once they reach coastal waters. For nitrogen, in contrast, the assumption is that emissions cause no impacts while in inland waters but cause eutrophication once they reach the sea.

To value the impacts of eutrophication as a consequence of nutrient emissions, we start from the share of inland water bodies that is in a moderate, poor or bad ecological status. In Germany, this applies to a share of 90% and 71% for running and standing waters, respectively (UBA 2022c, 2022d). Based on the surface area of these water bodies this results in an overall share of 80%. For these water bodies we assume that on average 50% of the value of ecosystem services are lost as a result of eutrophication, which is expected to underestimate the effects for water bodies with poor or bad ecological status and overestimate them in water bodies of moderate ecological status, but provides a conservative estimate on average. To monetize the loss of ecosystem services, we rely on studies estimating the overall value of the affected ecosystems and ecosystems services and assume that the abovementioned 50% of the overall value are lost as a consequence of eutrophication. The monetized loss of ecosystem services across all water bodies are then related to the overall emissions of nitrogen and phosphorus, to arrive at value factors per kg of nitrogen and phosphorus emissions.

A similar approach is applied to the valuation of impacts on marine waters. For the Baltic Sea we base the estimate of the affected surface on data from the European Environment Agency (EEA, 2019). The EEA indicator „direct effects of nutrient enrichment“ shows that approximately 97% of the surface of the Baltic Sea have a moderate or poor ecological status. Assuming again that eutrophication leads to a loss of 50% of ecosystem services on average, this results in an overall loss of 48%. The monetization is based on studies valuing the affected ecosystems and ecosystem services. This impact is assessed based on nitrogen and phosphorus emissions from HELCOM (2021).

For the North Sea, the same approach yields an affected surface area of 12% (EEA, 2019), emission volumes are taken from OSPAR (Axe et al., 2022). The values for the Baltic vs. North Sea differ significantly due to their geological differences, with the Baltics being an inland sea with very little exchange with the open oceans, thereby leading to more pronounced impacts. Hence, the average values for impacts on maritime waters overestimate the impacts on the North Sea but underestimate the impacts on the Baltic Sea.

7 Agriculture

Agriculture does not only provide food, energy and raw materials. With an area share of 50% in Germany, it also shapes the landscape and affects climate and ecosystems. The environmental costs of agriculture stem from a number of impacts, most but not all of them more pronounced for intensive forms of agriculture:

- greenhouse gas emissions, both directly from animal husbandry, the use of machinery, vehicles etc., and indirectly from land use change;
- nutrient emissions into the soil, water and atmosphere via various processes in the upstream and downstream value chains; the intensive use of fertilizers and animal husbandry (manure) leads to the contamination of ground- and surface waters, loss of biodiversity and damage to human health;
- direct impacts of intensive agricultural production processes on biodiversity and ecosystems as well as on agricultural soils.

Overall, agriculture is considered one of the driving factors of the loss of habitats for animals and plants. However, for the economic valuation of the impacts of agriculture on biodiversity and most ecosystem services, robust value factors are currently not available (see Chapter 9).

This chapter is based on Karzai and Hirschfeld (2024) and focuses on the impacts of agriculture related to greenhouse gases, nitrogen and phosphorus as well as air pollutant emissions.

7.1 Value Factors for Agricultural Products

Table 25: Value factors for agricultural animal products from conventional production (excluding the impact on biodiversity, most ecosystem services & animal welfare)

Product	Aggregated value factors €$_{2025}$/kg (1% PRTP)	Aggregated value factors €$_{2025}$/kg (0% PRTP)
Milk	0.63	1.35
Hard cheese (before sale)	6.65	12.46
Beef (slaughter weight)	33.51	52.40
Beef (with dairy cattle -slaughter weight)	7.00	11.80
Pork (slaughter weight)	5.83	9.38
Poultry (slaughter weight)	3.16	6.43
Eggs	2.34	4.11

Source: Karzai and Hirschfeld (2024), own calculations.

The values in the table are based on the emission factors in Korteland et al. (2023)[25], which use emission factors from Life Cycle Analysis (LCA) from the Agri-footprint database (Mérieux

[25] In order to improve the comparability of the values and to ensure uniformity of the assumptions, system boundaries and levels of consideration for the emission values, we follow the recommendation of Bieler and Sutter (2019) of using data from a single data source.

NutriSciences Blonk n. d), and Ecologic (unpublished, emission factors based on Rösemann et al., 2021) for Germany-specific values. The emission factors are then monetized based on the value factors in this handbook. The calculations include emissions up to the farm-gate and cover the following effects:

- Greenhouse gas emissions (CO2-eq);
- Eutrophication potential for marine and coastal waters (N-eq);
- Eutrophication potential for inland waters (P-eq);
- Particulate matter emissions (PM10);
- Volatile organic compounds (NMVOC).

Due to a lack of data, the value factors do not cover effects on biodiversity beyond those of eutrophication, see Chapter 6 for details. Korteland et al. (2023) also include emission data for organic production. However, since the data is too scarce to derive national values, we do not include them here.

Table 25 contains values for animal products only. These show the absolute impacts and allow comparisons between the impacts of different animal products. Impacts for plant-based products are not available from Korteland et al. (2023), but only from less recent data with a different scope of included environmental impacts (mainly GHG). Since this would prevent a meaningful comparison, we refrain from including impacts for plant-based products here. They can, however, be obtained by applying the value factors of this handbook to emission factors where available.

7.2 Value Factors for Animal Places

In addition to the value factors per product in Table 25, the costs resulting from greenhouse gas and air pollutant emissions for animal places[26] in a company or region can be calculated by multiplying the value factors of Chapters 2 and 3 with the emission factors per animal species, animal place and year available from the German Informative Inventory Report (UBA 2023d).

7.3 Value Factors for Fertilizer Use

Fertilizer is used in the agricultural practice to provide plants with the necessary nutrients for their growth. However, the optimal amount of nutrients per hectare is highly sensitive to a wide range of parameters such as the crop, location, soil properties, weather conditions etc., making it difficult to specify the optimal dosage in a more general way. From the difficulty in determining the optimal amount of fertilizer per hectare, together with the excess amounts of manure from animal husbandry in Germany, it follows that often too much fertilizer is used per hectare and thus too many nutrients are introduced onto the fields. As the plants can only absorb a certain amount of nutrients, the excess is either washed off by rain and transported into surface and ground waters or becomes airborne through wind or mechanical soil cultivation processes.

The values in Table 26 indicate value factors for the total amount of the applied nutrients, i.e. without assessing which share is absorbed by the plants and how much is emitted into the atmosphere and hydrosphere.

[26] Animal places refers to the number of animals kept by a company or in a region, usually as an annual average.

Table 26: Value factors of the application of nitrogen and phosphorus fertilizers in agriculture

Substance	Value factors (in €$_{2025}$/kg applied)
Nitrogen (1% PRTP)	8.40
Nitrogen (0% PRTP)	12.00
Phosphorus	22.27

Source: Own calculation based on Karzai and Hirschfeld (2024).

The value factors are computed by first multiplying average nutrient inputs per hectare[27] with the total agricultural area. These numbers are combined with the data of the German National Nitrogen Budget in Bach et al. (forthcoming) on the amounts of nitrogen and of Modeling of Regionalied Emissions (MoRE) in Fuchs et al. (2022) on the amounts of phosphorus that are annually emitted to the relevant environmental compartments (atmosphere, groundwater and surface water) as a consequence of fertilizer use in Germany. Using the value factors in this handbook on air pollutants and N and P inputs from Chapters 3 and 6, we compute the total damage arising from the N and P emissions and run-off in the different environmental compartments, which can then be broken down to value factors per kg of nutrient applied to agricultural land.

It should be noted that the modelling of the nutrient surplus flows underlying the value factors in Table 26 is explicitly based on German data. This differs from the emission factors in Korteland et al. (2023) used for Table 25, which are largely based on the Agri-Footprint LCA database. Due to a lack of data this inconsistency could not be addressed.

7.4 Value Factors for Nutrient Surpluses on Agricultural Land

Should the specific nutrient absorption capacity be known – and thus also the amount of excess nutrients – these excess quantities can be valued directly, based on the value factors for the effects of emissions into the relevant compartments atmosphere, groundwater and surface water. This valuation, however, is based on a general impact pathway for nutrient surpluses into environmental compartments[28], local pathways may differ depending on geological and hydrological conditions as well as the weather.

Table 27: Value factors of nutrient surpluses on agricultural land

Substance	Value factors (in €$_{2025}$/kg)
Nitrogen (1% PRTP)	21.06
Nitrogen (0% PRTP)	28.82
Phosphorus	437

Source: Own calculation based on Karzai and Hirschfeld (2024).

The value factors in Table 27 are based on the value factors in Chapters 2 and 6 but normalized to 1kg of N in the different nitrogen compounds.

[27] Data for N: BMELH, o. J.; data for P: Destatis, 2022.
[28] For P surpluses it is assumed that all surpluses generate eutrophication in inland surface waters (cf. Karzai et al. 2025), while for N surpluses we assume impacts according to the share of N-flows in Bach et al. (forthcoming).

7.5 Methodological Background

The value factors in this chapter are based on emission factors of products (e.g., Agri-food database) or agricultural practices (e.g., Bach et al., forthcoming) and the value factors for emissions of greenhouse gases, nitrogen, phosphorus etc. in this handbook. It should be emphasized, however, that none of the value factors in this chapter includes all the environmental impacts caused by the respective products or practices. In particular, impacts on ecosystems and biodiversity, but also water and soil beyond eutrophication of aquatic ecosystems are not included due to a lack of data. That means, for example, that the impacts of land-use change or use of pesticides, which are significant, are omitted.

The value factors on fertilizer use and nutrient surpluses are average values in two respects:

- They reflect average damages at national level rather than region-specific effects. That means, i.a., that the costs of applying fertilizer do not account for the significant differences in nitrogen and phosphorus inputs per hectare of agricultural land across Germany (see, e.g., Häußermann et al., 2019; UBA, 2023b). Similarly, the costs of nutrient surpluses do not account for regional differences in the background concentration levels of nitrogen and phosphorus in surface waters.
- They are based on the simplifying assumption that damage is linear in the amount of nitrogen and phosphorus applied, that is, damages are independent of, e.g., the existing eutrophication level. When the value factors are applied to specific local situations, therefore, the availability of local data on nutrients and impacts should be assessed.

An alternative approach to determining the environmental costs of phosphorus fertilization at specific locations is based on the use of phosphorus content classes (“Phosphorgehaltklassen”) A - E (Verband Deutscher Landwirtschaftlicher Untersuchungs- und Forschungsanstalten, 2018, 2015). These content classes are used to subdivide soils according to their phosphorus content, whereby the (natural) phosphorus content in the soil increases from class A to E. For content classes A and B the phosphorus content is assumed to be very low to low, so that phosphorus inputs to these areas may even be higher than the amount absorbed by plants without incurring environmental costs due to leaching, etc. Content class C is the optimum. Here it is recommended that the same amount of phosphorus is added to the soil as is removed (e.g, through crop cultivation). If more phosphorus is added to these soils than is removed, it can be assumed that the use of fertilizers results in environmental costs. This means that in these cases, phosphorus fertilization should also be assessed accordingly. In the case of content classes D and E, the phosphorus content is so high that phosphorus fertilization should take place below the removal rate or is not at all necessary from a crop cultivation perspective. Therefore, any application of phosphorus fertilizer is directly associated with environmental costs. If specific phosphorus data is available, the nutrient surplus can be calculated and valued.

8 Building Materials

Buildings cause significant direct and indirect environmental impacts along the life cycle, that is, during their construction, use, maintenance, demolition and disposal stages. In addition to the building materials themselves, these impacts depend on the kind of building, its type of use, transportation and maintenance technologies, recycling rates etc. Accordingly, value factors for building materials need to be put in perspective to the use and end-of-life stages of the building. For example, a better insulated building may have higher impacts from material use, but lower impacts during the use phase.

At present, due to data limitations it is not possible to recommend average, yet comprehensive value factors for building materials. Instead, based on the work by Bruinsma et al. (2024), this chapter discusses the key challenges for deriving value factors for building materials and provides illustrative examples for their use.

To properly asses the environmental impacts from buildings and building materials, a complete life-cycle assessment needs to be based on specific data for all lifecycle stages, and a consideration of all relevant impact categories. Unfortunately, LCA databases usually do not provide complete data. Even for the construction phase, LCA data tends to be incomplete regarding the initial stages of the supply chain (raw material extraction and processing), in particular with regard to impacts on biodiversity, pollution and water. As analyzed by Bruinsma et al. (2024) in their research for this handbook, most up-to-date databases for building materials follow the Product Environmental Footprint method as mandated by DIN EN15804+A2. Under DIN EN 15804+A2 ten impact categories are mandatory to be included in the analysis, while other relevant impact categories such as air pollution, land use and toxicity are only optional. Therefore, a vast majority of recent and publicly available environmental databases for building materials, such as ÖKOBAUDAT, do not provide data for (most of) these important but (currently) optional impact categories. Accordingly, the actual impacts of building materials cannot be properly assessed, as they may be grossly underestimated. In addition, the extent to which impacts are underestimated varies significantly between building materials and impact categories depending on the relevance of an impact for the respective material. As a consequence, comparing only the mandatory impacts of different materials does not give a reliable indication of the magnitude or relation of overall impacts. As suggested by Bruinsma et al (2024), it is possible to approximate the effect of the omitted impact categories by relying on data from other sources, which do provide data on the impact categories optional under DIN EN 15804+A2. However, this approach only allows for a rough estimate of the influence of the omitted impact categories and may lead to inconsistencies as the data are not fully compatible. We have therefore decided against recommending average value factors for building materials.

It is, however, possible to use LCA data in combination with the value factors in this handbook to monetize specific impacts along the value chain. Table 28 and Table 29 below illustrate this approach for concrete and steel materials for the stages covered in ÖKOBAUDAT and the impacts covered in this handbook.

Life-cycle databases like the German public LCA database ÖKOBAUDAT use standardized life cycle stages (or 'modules') for building materials, in case of ÖKOBAUDAT according to the classification in DIN EN 15804+A2:

- the product stage (production and transport of raw materials and manufacturing (modules A1-A3),
- the construction process stage (transport and construction-installation process) (modules A4-A5),
- the use stage (modules B1-B7),
- the end-of -life stage (modules C1-C4) and
- benefits and burdens beyond the system boundary (module D).

As one example, for Concrete 45/55 ÖKOBAUDAT covers the lifecycle stages A1-A5, B1, C1-C4 and D. For stages A1-A3 that are relevant for Concrete 45/55 as a material input, ÖKOBAUDAT yields the following emission factors for impacts covered by this handbook, which can be combined with the respective value factors from Chapters 2 and 6:

Table 28: Emission and value factors per tonne of Concrete 45/55, LCA A1-A3 (manufacturing)

Impact	Unit of emissions	Emission factor	Value factor for respective impact	Environmental costs in $€_{2025}/t_{material}$ (1% PRTP for GHG emissions)	Environmental costs in $€_{2025}/t_{material}$ (0% PRTP for GHG emissions)
Total Global Warming Potential	t CO_2-eq / t	0.114	345$€_{2025}$ /t CO_2-eq (1%PRTP) 990$€_{2025}$/t CO_2-eq (0% PRTP)	39.2	112.6
Eutrophication potential inland waters	kg P-eq / t	0.00013	437,300 $€_{2025}$/t P-eq	0.0567	0.0567
Eutrophication potential coastal and marine waters	kg N-eq / t	0.056	24,900 $€_{2025}$/ t N-eq	1.39	1.39
Value factor € / $t_{material}$				**40.49**	**114.06**

The value factors have been transformed as follows:
kg CO_2-eq/1m³ is equivalent to kg CO_2-eq/2,400kg, which is equivalent to t CO_2-eq/2,400t, and is recalculated as t CO_2-eq/t
kg P-eq/1m³ is equivalent to kg P-eq/2,400kg, and is recalculated as kg P-eq/t
kg N-eq/1m³ is equivalent to kg N-eq/2,400kg, and is recalculated as kg N-eq/t
Source: Own calculation based on ÖKOBAUDAT according to DIN EN 15804+A2 (Sphera MLC).

As another example, for one tonne of steel section, the manufacturing stages A1-A3 return the following emission and value factors:

Table 29: Emission and value factors per tonne of Steel section, LCA stages A1-A3 (manufacturing)

Impact	Unit of emissions	Emission factor	Value factor for respective impact	Environmental costs in €$_{2025}$/t$_{material}$ (1% PRTP for GHG emissions)	Environmental costs in €$_{2025}$/t$_{material}$ (0% PRTP for GHG emissions)
Total GWP	t CO_2-eq / t$_{material}$	2.922	345€$_{2025}$ /t CO_2-eq (1%PRTP) 990€$_{2025}$/t CO_2-eq (0% PRTP)	1,008.1	2,892.8
Eutrophication inland waters	kg P-eq / t$_{material}$	<0.0001	437,300 €$_{2025}$/t P-eq	0.0001	0.0001
Eutrophication coastal and marine waters	kg N-eq / t$_{material}$	0.0016	24,900 €$_{2025}$/ t N-eq	0.0387	0.0387
Value factor € / t$_{material}$				**1,008.14**	**2,892.84**

Source: Own calculation based on ÖKOBAUDAT according to DIN EN 15804+A2 (Sphera MLC).

As explained above, these value factors include only a limited set of impacts and must be expected to underestimate impacts, in particular at the beginning of the value chain. Hence, they can only be used for the assessment of the stages and impacts that are explicitly included in the emission factors. In addition, emission factors in LCA databases represent averages if not stated otherwise. For the analysis of a specific product, LCA data for this particular product should be used if available.

9 Ecosystem Services and Biodiversity

All human activity depends on the services ecosystems provide, and the biodiversity these ecosystems are based on. Ecosystems and their services are directly or indirectly affected by most or all environmental pressures including land use and land use change, climate change, pollution to water, air and soil, and water scarcity. The impacts on ecosystems depend on local, seasonal and temporal parameters, sometimes down to the time of day (e.g., light or noise pollution). They also depend on how the different pressures interact in a certain region or season.

Accordingly, specifying the impacts that pressures have on ecosystems and biodiversity is more complex than, e.g., specifying the relationship between GHG emissions and global warming. However, given that many economic and political activities have consequences far beyond the local environment, it is nevertheless necessary to specify these impacts in a globally applicable and comparable way, if we are to include them in political and economic decision making. This will inevitably involve certain compromises and inaccuracies in the resulting metrics, which have to be weighed against the advantages of integrating ecosystem and biodiversity impacts into policy and investment decisions[29].

Ecosystem Services (ESS)

The amount of studies that value ecosystem services is continuously increasing. The number and quality of these studies differ across valuation methods, ecosystem services and regions. While data may be readily available on certain provisioning and cultural services in industrialized countries, reliable data on, e.g., non-use services in regions with predominantly indigenous and subsistence cultures is harder to find. In addition, since individual studies are usually not normalized to, e.g., purchasing power and assessment method, results from databases are difficult to compare.

The Ecosystem Services Valuation Database (ESVD) provides the largest open access collection of scientific studies on the economic valuation of ecosystem services available to date and, in our view, is the best existing reference. If the economic valuation of an ecosystem service is required for a particular situation or decision that is covered by the ESVD studies, and the ecosystem service is only compared to similar services under similar circumstances (e.g., similar socio-economic conditions and ecosystems), the database provides valuable guidance.

It is, however, currently more difficult to use the ESVD data to estimate comparable, aggregate values across different ecosystems, geographical regions, seasons, socio-economic contexts etc. With different cost assessment concepts being used in the different (meta-)studies included, the results also need to be differentiated based on the applicable approach (damage costs, mitigation cost, restoration costs etc.). In addition, the number and quality of studies in the database reflect the different levels of complexity in valuing different ecosystem services and in different countries, which pose further challenges for comparisons across regions, ecosystems and ecosystem services.

Based on our analysis of the ESVD, we came to the conclusion that the available data is not yet solid enough for the purposes of this handbook. We, nevertheless, fully support the aim of the ESVD and are confident that its further development will contribute to providing better data for

[29] This chapter has been informed by the research report by Karzai et al. (2024).

the economic valuation of ecosystem services. For the application of value transfers between closely related services and contexts (regions etc.) it can already give helpful guidance now.

Biodiversity

The economic valuation of biodiversity is even more complex than for most ecosystem services. Currently, there is no uniform understanding of if and how biodiversity can be measured with only one consistent and globally comparable, yet locally adaptable indicator. From a natural science perspective, biodiversity is a complex concept that requires a number of indicators to be properly described. For economic or financial decision making, however, a multi-dimensional indicator poses practical difficulties, in particular in aggregations and comparisons, either with other environmental effects or with financial data.

We analysed a number of available concepts (Hemerobia, Potentially Disappeared Fraction of Species (PDF), Mean Species Abundance (MSA), Biodiversity Intactness Index (BII), Species Threat Abatement and Recovery Metrics (STAR), Living Planet Index (LPI), Artenvielfalt und Landschaftsqualität) with regard to the characteristics an indicator has to meet to serve as the basis for a value factor:

- The indicator needs to be cardinal rather than ordinal. Only then it can be ensured that even small changes in biodiversity can be reflected in the indicator and that the distance between different values of the indicator can be interpreted.
- The indicator needs to be globally applicable and comparable. That is, it has to be able to reflect to a reasonable extent that, e.g., certain ecosystems contain less species in their primary state than others without being less valuable, certain species are more strictly confined to specific climatic zones or geographical regions and hence less resilient to the loss of habitat or climatic change, certain ecosystems are more sensitive to the loss of individual species etc., even if we currently lack some of the data to determine such differences.
- The indicator needs to be monetizable, i.e. be in a form that can be used in economic valuation of non-market values (such as willingness to pay (WTP) or Willingness to accept (WTA) etc.).

In our view, none of the currently available indicators fully complies with all of these criteria. The most promising candidates identified through our research so far, are those that compare a cardinal indicator of current biodiversity like the number or abundance of species present in an ecosystem with the same cardinal indicator in a reference state of the same ecosystem. Examples include PDF, MSA and BII.

Apart from the lack of global physical data and monetization studies that can be aggregated, the crucial conceptual question of the right reference state of the ecosystem remains for indicators that involve a comparison, such as PDF, MSA or the BII. For PDFs, the difference between the reference state of the ecosystem and the current state determines the size of the fraction that has “disappeared” from the reference state, while for BII it determines what “intact” means (a BII of 100%) and for MSA what “full abundance” means. The indicators change substantially depending on whether the reference ecosystem is the pristine state of the earth before humans appeared (and even then, differing according to the chosen point in time), the biodiversity-rich but cultivated landscape modern nature protection policies may aim for, the “domesticized” landscape many citizens may prefer over the pristine state in a discrete choice experiment, or any other. Although the pristine state of the earth seems a natural and globally uniform reference point, it leaves the question, among others, as to the meaning of such a reference in areas where human influence has formed the landscape for thousands of years and will continue to do so in the foreseeable future. Other references, like the state of ecosystems envisaged in policy strategies on nature protection, are prone to baseline shift, lack of scientific basis, incomparability between countries and regions etc.

Given that the loss of ecosystems and biodiversity is strongly interlinked with climate change and just as threatening to the future of humanity, we strongly support and aim at contributing to progress in measuring and valuing biodiversity as well as its inclusion in economic and political decision making. At the moment, however, the available methods and data are not yet mature enough to support a value factor for biodiversity being included in this handbook.

10 Water Pollution and Water Withdrawal

Water pollution and water scarcity are pressing problems in many regions of the world. Germany has traditionally focused more on water pollution, with water scarcity being perceived as virtually non-existent. This has changed as a result of climate change, with local restrictions on water use having been introduced in recent years and being expected to become more widespread in the future. In addition, the environmental costs of global water pollution and scarcity are an important issue for German businesses with global operations and value chains. While water pollution and water withdrawal tend to be measured and assessed separately, they are closely interconnected: water withdrawal increases the concentration of harmful substances in water bodies, leading to more harmful pollution levels[30].

Water Pollution

Water pollution includes emissions of contaminants and nutrients into the water, but also thermal pollution. The environmental and health effects of water pollution depend on a number of factors, e.g. pre-emission pollution levels, temperature, water level, affected ecosystems, ecosystem services derived from the water body, the combination of emitted pollutants etc. After analyzing the available data bases and scientific literature, we reached the conclusion that data and methods are currently not sufficient to develop value factors that can account for these different parameters in a satisfactory way, that is, that capture their average or main effects. With the exception of the value factors regarding eutrophication in Chapter 6, we therefore cannot recommend value factors that are fit for purpose in a more general context (regional/national/global).

Water Withdrawal

The effects of water withdrawal are about as complex as those of water pollution. Water withdrawn from a water body can be “consumed” or returned to the water body, usually with a different temperature and/or chemical and biological composition (added pollutants, lost organisms etc.). The effects withdrawal has on the affected water body depend – as for pollution – on the state of the water body before the withdrawal, the change in chemical and biological composition caused by the withdrawal if the water is returned, the affected ecosystems and ecosystem services etc. Based on our analysis of the available data and literature we again reached the conclusion that data and methods are currently not sufficient to develop value factors that can capture the main effects of these different parameters. Accordingly, in this handbook we do not recommend value factors that can be used in a more general context.

Research Gap

To arrive at average value factors for water pollution and withdrawal at an aggregate level, new models mapping the impacts of pollution and withdrawal have to be developed. These models do not need to account for all details of the potential effects in every specific body of water. However, they need to consider broad categories like size and state of water bodies or seasonal effects (summer/winter or dry season/rainy season) in order to be able to aggregate the data of studies from individual water bodies into more generally applicable value factors.

[30] This chapter has been informed by the research report Görlitz et al. (2024).

11 Appendix

This appendix relates to the tables in Section 5.1 and provides more differentiated value factors. Table 30 and Table 31 display the value factors according to Euro standards for the different vehicle types[31]. For the different types of trucks, an additional distinction is made according to transport weight, and an additional category is included for heavy goods vehicles. In order to make the tables easier to navigate, the calculated value factors for construction, maintenance, disposal and fuel supply are summarized according to the life cycle phases.

Table 30: a) Value factors transport: differentiated by emission category (Euronorm) for the different vehicle types, 0% PRTP for GHG value factors, in €-cent$_{2025}$ / vehicle kilometer

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 0% PRTP							
Vehicle category	Euro standard	Operation			Pre-processes		Total
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Infra-structure and vehicles	Energy supply	
Car (Diesel)	Euro 0	20.32	6.68	0.20	8.20	5.69	41.09
	Euro 1	18.58	4.65	0.20	8.20	5.21	36.83
	Euro 2	18.81	5.39	0.20	8.20	5.27	37.86
	Euro 3	16.99	6.55	0.20	8.20	4.76	36.70
	Euro 4	17.40	4.55	0.20	8.20	4.88	35.22
	Euro 5	16.76	3.59	0.20	8.20	4.70	33.44
	Euro 6	17.82	1.23	0.20	8.20	5.00	32.45
Car (Petrol)	Euro 0	18.94	7.11	0.20	8.00	7.67	41.92
	Euro 1	18.40	5.40	0.20	8.00	7.41	39.41
	Euro 2	18.15	2.90	0.20	8.00	7.38	36.63
	Euro 3	17.45	1.02	0.20	8.00	7.15	33.83
	Euro 4	16.88	0.64	0.20	8.00	6.92	32.65
	Euro 5	15.57	0.20	0.20	8.00	6.38	30.36
	Euro 6	15.68	0.21	0.20	8.00	6.43	30.51
Small motorbike (Petrol)	Euro 0	9.58	3.71	0.07	3.49	3.52	20.38
	Euro 1	8.27	1.64	0.07	3.49	3.23	16.71
	Euro 2	6.22	0.95	0.07	3.49	2.33	13.07
	Euro 3	4.88	0.46	0.07	3.49	1.79	10.70
Motorbike (Petrol)	Euro 0	14.13	1.47	0.07	5.31	4.70	25.67
	Euro 1	13.21	1.29	0.07	5.31	4.40	24.28
	Euro 2	12.37	1.23	0.07	5.31	4.15	23.13
	Euro 3	9.38	0.15	0.07	5.31	3.11	18.02
Light commercial vehicle (Petrol)	Euro 0	30.19	9.72	0.20	9.16	11.57	60.85
	Euro 1	29.27	12.77	0.20	9.16	11.23	62.63
	Euro 2	23.89	4.26	0.20	9.16	9.16	46.67
	Euro 3	20.90	1.59	0.20	9.16	7.99	39.84
	Euro 4	18.73	0.72	0.20	9.16	7.16	35.96

[31] The differentiation of emission factors according to European standards is based on HBEFA v3.3.

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 0% PRTP							
Vehicle category	Euro standard	Operation			Pre-processes		Total
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Infra-structure and vehicles	Energy supply	
	Euro 5	19.16	0.39	0.20	9.16	7.32	36.23
	Euro 6	17.45	0.25	0.20	9.16	6.67	33.74
Light commercial vehicle (Diesel)	**Euro 0**	34.02	10.69	0.20	9.16	10.36	64.43
	Euro 1	31.88	8.47	0.20	9.16	9.71	59.43
	Euro 2	29.04	7.16	0.20	9.16	8.85	54.40
	Euro 3	22.64	9.36	0.20	9.16	6.90	48.26
	Euro 4	23.39	7.61	0.20	9.16	7.13	47.49
	Euro 5	25.39	6.17	0.20	9.16	7.74	48.65
	Euro 6	24.15	1.49	0.20	9.16	7.36	42.36
Public bus	**Euro 0**	101.87	66.77	2.05	26.22	34.70	231.61
	Euro 1	92.88	44.60	2.05	26.22	31.63	197.37
	Euro 2	99.55	47.07	2.05	26.22	33.89	208.77
	Euro 3	109.39	41.54	2.05	26.22	37.24	216.44
	Euro 4	112.51	30.10	2.05	26.22	38.30	209.18
	Euro 5	104.30	25.21	2.05	26.22	35.52	193.30
	Euro 6	92.87	6.20	2.05	26.22	31.63	158.97
Coach	**Euro 0**	83.44	58.95	1.24	26.01	31.53	201.16
	Euro 1	83.16	44.04	1.24	26.01	31.42	185.87
	Euro 2	81.51	42.55	1.24	26.01	30.79	182.10
	Euro 3	84.67	35.56	1.24	26.01	31.98	179.46
	Euro 4	79.38	23.72	1.24	26.01	29.98	160.32
	Euro 5	74.65	26.08	1.24	26.01	28.21	156.19
	Euro 6	66.38	3.40	1.24	26.01	25.09	122.11
Heavy goods vehicle (< = 7.5t)	**80ties**	52.16	31.50	1.08	9.16	10.47	104.37
	Euro-I	45.07	20.41	1.08	9.16	9.04	84.76
	Euro-II	39.49	19.72	1.08	9.16	7.92	77.38
	Euro-III	40.75	15.10	1.08	9.16	8.18	74.26
	Euro-IV EGR	42.20	12.90	1.08	9.16	8.47	73.81
	Euro-IV SCR	41.76	8.43	1.08	9.16	8.38	68.80
	Euro-V EGR	39.16	14.81	1.08	9.16	7.86	72.07
	Euro-V SCR	38.38	6.74	1.08	9.16	7.70	63.06
	Euro-VI	33.21	0.45	1.08	9.16	6.67	50.56
Heavy goods vehicle (>7.5t-12t)	**80ties**	61.38	37.57	1.08	12.37	14.59	126.99
	Euro-I	56.80	24.16	1.08	12.37	13.49	107.91
	Euro-II	52.00	23.76	1.08	12.37	12.35	101.57
	Euro-III	52.68	17.78	1.08	12.37	12.51	96.43
	Euro-IV EGR	48.23	13.01	1.08	12.37	11.46	86.14
	Euro-IV SCR	47.71	10.47	1.08	12.37	11.33	82.97
	Euro-V EGR	44.45	13.96	1.08	12.37	10.56	82.42

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 0% PRTP							
Vehicle category	Euro standard	Operation			Pre-processes		Total
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Infra-structure and vehicles	Energy supply	
	Euro-V SCR	43.57	9.30	1.08	12.37	10.35	76.67
	Euro-VI	38.23	0.56	1.08	12.37	9.08	61.33
Heavy goods vehicle (>12t-14t)	**80ties**	64.67	39.46	1.08	12.37	15.37	132.95
	Euro-I	60.54	27.05	1.08	12.37	14.38	115.43
	Euro-II	55.59	26.53	1.08	12.37	13.20	108.78
	Euro-III	57.44	20.60	1.08	12.37	13.64	105.14
	Euro-IV EGR	52.62	16.63	1.08	12.37	12.50	95.20
	Euro-IV SCR	52.01	9.88	1.08	12.37	12.36	87.71
	Euro-V EGR	50.05	14.72	1.08	12.37	11.90	90.12
	Euro-V SCR	49.03	7.94	1.08	12.37	11.65	82.07
	Euro-VI	43.66	0.53	1.08	12.37	10.38	68.03
Heavy goods vehicle (>14t-20t)	**80ties**	72.44	43.63	1.08	32.49	25.78	175.42
	Euro-I	68.19	30.45	1.08	32.49	24.25	156.46
	Euro-II	62.80	29.62	1.08	32.49	22.34	148.33
	Euro-III	65.03	23.30	1.08	32.49	23.13	145.03
	Euro-IV EGR	61.26	19.92	1.08	32.49	21.79	136.53
	Euro-IV SCR	60.56	11.68	1.08	32.49	21.54	127.35
	Euro-V EGR	57.90	21.27	1.08	32.49	20.60	133.34
	Euro-V SCR	56.76	11.91	1.08	32.49	20.20	122.44
	Euro-VI	50.19	1.01	1.08	32.49	17.86	102.63
Heavy goods vehicle (>20t-26t)	**80ties**	93.19	58.40	1.08	32.49	33.15	218.30
	Euro-I	87.81	41.43	1.08	32.49	31.24	194.05
	Euro-II	80.67	40.28	1.08	32.49	28.69	183.21
	Euro-III	81.17	31.58	1.08	32.49	28.87	175.19
	Euro-IV EGR	76.25	23.91	1.08	32.49	27.12	160.84
	Euro-IV SCR	75.46	15.66	1.08	32.49	26.84	151.53
	Euro-V EGR	71.76	27.89	1.08	32.49	25.53	158.75
	Euro-V SCR	70.36	17.12	1.08	32.49	25.04	146.09
	Euro-VI	62.02	1.61	1.08	32.49	22.07	119.27
Heavy goods vehicle (>26t-28t)	**Euro-I**	95.72	42.50	1.08	32.49	34.05	205.85
	Euro-II	89.01	40.72	1.08	32.49	31.66	194.96
	Euro-III	88.67	32.05	1.08	32.49	31.54	185.83
	Euro-IV EGR	83.94	22.73	1.08	32.49	29.85	170.10
	Euro-IV SCR	83.11	18.97	1.08	32.49	29.56	165.20
	Euro-V EGR	79.41	24.53	1.08	32.49	28.25	165.76
	Euro-V SCR	77.82	16.75	1.08	32.49	27.69	155.83
	Euro-VI	69.33	1.42	1.08	32.49	24.67	129.00
Heavy goods vehicle (>28t-32t)	**Euro-I**	106.42	47.65	1.08	54.50	31.98	241.64
	Euro-II	99.20	45.55	1.08	54.50	29.81	230.14

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 0% PRTP							
Vehicle category	**Euro standard**	**Operation**			**Pre-processes**		**Total**
		Green-house gases	**Air pollutants Exhaust**	**Air pollutants Abrasion**	**Infra-structure and vehicles**	**Energy supply**	
	Euro-III	99.10	35.47	1.08	54.50	29.77	219.92
	Euro-IV EGR	93.55	25.31	1.08	54.50	28.11	202.56
	Euro-IV SCR	92.53	20.30	1.08	54.50	27.80	196.22
	Euro-V EGR	88.63	25.48	1.08	54.50	26.64	196.35
	Euro-V SCR	86.87	17.86	1.08	54.50	26.11	186.43
	Euro-VI	77.33	1.36	1.08	54.50	23.25	157.52
Heavy goods vehicle (>32t	**Euro-I**	113.92	50.74	1.08	54.50	34.23	254.48
	Euro-II	105.29	48.51	1.08	54.50	31.64	241.02
	Euro-III	104.55	37.78	1.08	54.50	31.41	229.34
	Euro-IV EGR	99.47	27.25	1.08	54.50	29.89	212.19
	Euro-IV SCR	98.39	21.47	1.08	54.50	29.56	205.01
	Euro-V EGR	93.74	27.53	1.08	54.50	28.18	205.04
	Euro-V SCR	91.86	19.07	1.08	54.50	27.61	194.12
	Euro-VI	81.91	1.54	1.08	54.50	24.62	163.66
Truck and trailer/semi-truck (>20-28t)	**80ties**	79.54	57.66	1.08	54.50	23.91	216.69
	Euro-I	74.44	35.27	1.08	54.50	22.37	187.67
	Euro-II	67.81	34.75	1.08	54.50	20.38	178.52
	Euro-III	68.84	28.84	1.08	54.50	20.68	173.96
	Euro-IV EGR	64.93	22.34	1.08	54.50	19.51	162.37
	Euro-IV SCR	64.26	15.90	1.08	54.50	19.31	155.05
	Euro-V EGR	59.54	20.87	1.08	54.50	17.90	153.90
	Euro-V SCR	58.36	13.64	1.08	54.50	17.54	145.13
	Euro-VI	52.47	0.87	1.08	54.50	15.77	124.70
Truck and trailer/semi-truck (>28-34t)	**80ties**	103.83	73.94	1.08	54.50	31.21	264.56
	Euro-I	98.64	45.15	1.08	54.50	29.64	229.02
	Euro-II	89.60	43.58	1.08	54.50	26.92	215.69
	Euro-III	90.99	35.89	1.08	54.50	27.34	209.81
	Euro-IV EGR	87.19	27.84	1.08	54.50	26.20	196.81
	Euro-IV SCR	86.27	17.38	1.08	54.50	25.92	185.16
	Euro-V EGR	81.85	23.92	1.08	54.50	24.61	185.97
	Euro-V SCR	80.20	13.35	1.08	54.50	24.11	173.26
	Euro-VI	72.19	0.85	1.08	54.50	21.70	150.33
Truck and trailer/semi-truck (>34-40t)	**80ties**	116.87	73.87	1.08	54.50	35.12	281.44
	Euro-I	111.03	51.84	1.08	54.50	33.36	251.82
	Euro-II	102.56	49.85	1.08	54.50	30.81	238.81
	Euro-III	101.95	40.06	1.08	54.50	30.63	228.24
	Euro-IV EGR	98.19	30.23	1.08	54.50	29.50	213.50
	Euro-IV SCR	97.13	19.50	1.08	54.50	29.18	201.40
	Euro-V EGR	93.37	33.72	1.08	54.50	28.07	210.75

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 0% PRTP							
Vehicle category	Euro standard	Operation			Pre-processes		Total
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Infra-structure and vehicles	Energy supply	
	Euro-V SCR	91.57	19.21	1.08	54.50	27.53	193.89
	Euro-VI	81.93	1.26	1.08	54.50	24.63	163.42

Engines that were in circulation before the introduction of the exhaust emission standard are designated Euro 0 for cars and 80ties for trucks in HBEFA 3.3.
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

Table 31: b) Value factors transport: differentiated by emission category (Euronorm) for the different vehicle types, 1% PRTP for GHG value factors, in €-cent$_{2025}$ / vehicle kilometer

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 1% PRTP							
Vehicle category	Euro standard	Operation			Pre-processes		Total
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Infra-structure and vehicles	Energy supply	
Car (Diesel)	Euro 0	7.04	6.68	0.20	3.64	2.44	20.01
	Euro 1	6.45	4.65	0.20	3.64	2.23	17.18
	Euro 2	6.53	5.39	0.20	3.64	2.26	18.02
	Euro 3	5.90	6.55	0.20	3.64	2.04	18.33
	Euro 4	6.04	4.55	0.20	3.64	2.09	16.53
	Euro 5	5.82	3.59	0.20	3.64	2.02	15.27
	Euro 6	6.20	1.23	0.20	3.64	2.15	13.42
Car (Petrol)	Euro 0	6.60	7.11	0.20	3.55	3.37	20.83
	Euro 1	6.40	5.40	0.20	3.55	3.26	18.81
	Euro 2	6.30	2.90	0.20	3.55	3.24	16.20
	Euro 3	6.05	1.02	0.20	3.55	3.14	13.97
	Euro 4	5.85	0.64	0.20	3.55	3.04	13.29
	Euro 5	5.40	0.20	0.20	3.55	2.81	12.16
	Euro 6	5.43	0.21	0.20	3.55	2.83	12.22
Small motorbike (Petrol)	Euro 0	3.42	3.71	0.07	1.59	1.51	10.31
	Euro 1	3.04	1.64	0.07	1.59	1.39	7.74
	Euro 2	2.24	0.95	0.07	1.59	1.00	5.86
	Euro 3	1.74	0.46	0.07	1.59	0.77	4.64
Motorbike (Petrol)	Euro 0	4.91	1.47	0.07	2.48	2.02	10.95
	Euro 1	4.60	1.29	0.07	2.48	1.89	10.33
	Euro 2	4.32	1.23	0.07	2.48	1.78	9.89
	Euro 3	3.26	0.15	0.07	2.48	1.33	7.29

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 1% PRTP							
Vehicle category	**Euro standard**	**Operation**			**Pre-processes**		**Total**
		Green-house gases	**Air pollutants Exhaust**	**Air pollutants Abrasion**	**Infra-structure and vehicles**	**Energy supply**	
Light commercial vehicle (Petrol)	**Euro 0**	10.50	9.72	0.20	4.16	5.09	29.66
	Euro 1	10.23	12.77	0.20	4.16	4.94	32.30
	Euro 2	8.34	4.26	0.20	4.16	4.03	20.98
	Euro 3	7.25	1.59	0.20	4.16	3.51	16.71
	Euro 4	6.49	0.72	0.20	4.16	3.15	14.72
	Euro 5	6.64	0.39	0.20	4.16	3.22	14.61
	Euro 6	6.05	0.25	0.20	4.16	2.93	13.59
Light commercial vehicle (Diesel)	**Euro 0**	11.79	10.69	0.20	4.16	4.45	31.29
	Euro 1	11.06	8.47	0.20	4.16	4.17	28.06
	Euro 2	10.08	7.16	0.20	4.16	3.80	25.39
	Euro 3	7.86	9.36	0.20	4.16	2.96	24.54
	Euro 4	8.12	7.61	0.20	4.16	3.06	23.15
	Euro 5	8.82	6.17	0.20	4.16	3.32	22.66
	Euro 6	8.40	1.49	0.20	4.16	3.16	17.41
Public bus	**Euro 0**	35.34	66.77	2.05	11.25	14.70	130.12
	Euro 1	32.22	44.60	2.05	11.25	13.40	103.52
	Euro 2	34.52	47.07	2.05	11.25	14.36	109.24
	Euro 3	37.92	41.54	2.05	11.25	15.78	108.54
	Euro 4	39.03	30.10	2.05	11.25	16.23	98.66
	Euro 5	36.25	25.21	2.05	11.25	15.05	89.81
	Euro 6	32.27	6.20	2.05	11.25	13.40	65.17
Coach	**Euro 0**	28.94	58.95	1.24	11.61	14.08	114.82
	Euro 1	28.84	44.04	1.24	11.61	14.03	99.76
	Euro 2	28.27	42.55	1.24	11.61	13.75	97.42
	Euro 3	29.36	35.56	1.24	11.61	14.28	92.04
	Euro 4	27.54	23.72	1.24	11.61	13.39	77.49
	Euro 5	25.95	26.08	1.24	11.61	12.59	77.48
	Euro 6	23.08	3.40	1.24	11.61	11.20	50.53
Heavy goods vehicle (< = 7.5t)	**80ties**	18.09	31.50	1.08	4.16	4.49	59.33
	Euro-I	15.63	20.41	1.08	4.16	3.88	45.16
	Euro-II	13.70	19.72	1.08	4.16	3.40	42.06
	Euro-III	14.13	15.10	1.08	4.16	3.51	37.98
	Euro-IV EGR	14.64	12.90	1.08	4.16	3.63	36.41
	Euro-IV SCR	14.49	8.43	1.08	4.16	3.60	31.75
	Euro-V EGR	13.61	14.81	1.08	4.16	3.37	37.04
	Euro-V SCR	13.34	6.74	1.08	4.16	3.31	28.62
	Euro-VI	11.54	0.45	1.08	4.16	2.86	20.09
	80ties	21.29	37.57	1.08	5.64	6.26	71.84
	Euro-I	19.70	24.16	1.08	5.64	5.79	56.38

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 1% PRTP							
Vehicle category	Euro standard	Operation			Pre-processes		Total
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Infra-structure and vehicles	Energy supply	
Heavy goods vehicle (>7.5t-12t)	Euro-II	18.03	23.76	1.08	5.64	5.30	53.82
	Euro-III	18.27	17.78	1.08	5.64	5.37	48.14
	Euro-IV EGR	16.73	13.01	1.08	5.64	4.92	41.38
	Euro-IV SCR	16.55	10.47	1.08	5.64	4.86	38.61
	Euro-V EGR	15.44	13.96	1.08	5.64	4.53	40.66
	Euro-V SCR	15.14	9.30	1.08	5.64	4.44	35.60
	Euro-VI	13.28	0.56	1.08	5.64	3.90	24.47
Heavy goods vehicle (>12t-14t)	80ties	22.44	39.46	1.08	5.64	6.60	75.22
	Euro-I	21.00	27.05	1.08	5.64	6.17	60.95
	Euro-II	19.28	26.53	1.08	5.64	5.67	58.21
	Euro-III	19.92	20.60	1.08	5.64	5.86	53.10
	Euro-IV EGR	18.26	16.63	1.08	5.64	5.36	46.98
	Euro-IV SCR	18.05	9.88	1.08	5.64	5.30	39.96
	Euro-V EGR	17.42	14.72	1.08	5.64	5.11	43.98
	Euro-V SCR	17.07	7.94	1.08	5.64	5.00	36.73
	Euro-VI	15.20	0.53	1.08	5.64	4.45	26.91
Heavy goods vehicle (>14t-20t)	80ties	25.13	43.63	1.08	14.93	11.06	95.83
	Euro-I	23.65	30.45	1.08	14.93	10.41	80.52
	Euro-II	21.78	29.62	1.08	14.93	9.59	77.00
	Euro-III	22.55	23.30	1.08	14.93	9.93	71.79
	Euro-IV EGR	21.26	19.92	1.08	14.93	9.35	66.53
	Euro-IV SCR	21.01	11.68	1.08	14.93	9.24	57.95
	Euro-V EGR	20.14	21.27	1.08	14.93	8.84	66.26
	Euro-V SCR	19.75	11.91	1.08	14.93	8.67	56.34
	Euro-VI	17.47	1.01	1.08	14.93	7.67	42.15
Heavy goods vehicle (>20t-26t)	80ties	32.32	58.40	1.08	14.93	14.22	120.95
	Euro-I	30.45	41.43	1.08	14.93	13.40	101.30
	Euro-II	27.98	40.28	1.08	14.93	12.31	96.58
	Euro-III	28.14	31.58	1.08	14.93	12.39	88.12
	Euro-IV EGR	26.45	23.91	1.08	14.93	11.64	78.00
	Euro-IV SCR	26.18	15.66	1.08	14.93	11.52	69.37
	Euro-V EGR	24.95	27.89	1.08	14.93	10.96	79.80
	Euro-V SCR	24.46	17.12	1.08	14.93	10.74	68.34
	Euro-VI	21.56	1.61	1.08	14.93	9.47	48.66
Heavy goods vehicle (>26t-28t)	Euro-I	33.20	42.50	1.08	14.93	14.61	106.32
	Euro-II	30.87	40.72	1.08	14.93	13.59	101.19
	Euro-III	30.74	32.05	1.08	14.93	13.53	92.34
	Euro-IV EGR	29.12	22.73	1.08	14.93	12.81	80.67
	Euro-IV SCR	28.83	18.97	1.08	14.93	12.68	76.49

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 1% PRTP							
Vehicle category	Euro standard	Operation			Pre-processes		Total
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Infra-structure and vehicles	Energy supply	
	Euro-V EGR	27.60	24.53	1.08	14.93	12.13	80.26
	Euro-V SCR	27.05	16.75	1.08	14.93	11.88	71.69
	Euro-VI	24.10	1.42	1.08	14.93	10.59	52.12
Heavy goods vehicle (>28t-32t)	Euro-I	36.91	47.65	1.08	24.80	13.72	124.18
	Euro-II	34.41	45.55	1.08	24.80	12.79	118.64
	Euro-III	34.36	35.47	1.08	24.80	12.78	108.49
	Euro-IV EGR	32.46	25.31	1.08	24.80	12.06	95.72
	Euro-IV SCR	32.11	20.30	1.08	24.80	11.93	90.23
	Euro-V EGR	30.83	25.48	1.08	24.80	11.43	93.64
	Euro-V SCR	30.22	17.86	1.08	24.80	11.21	85.18
	Euro-VI	26.91	1.36	1.08	24.80	9.98	64.13
Heavy goods vehicle (>32t	Euro-I	39.51	50.74	1.08	24.80	14.69	130.83
	Euro-II	36.52	48.51	1.08	24.80	13.58	124.49
	Euro-III	36.25	37.78	1.08	24.80	13.48	113.40
	Euro-IV EGR	34.51	27.25	1.08	24.80	12.83	100.47
	Euro-IV SCR	34.14	21.47	1.08	24.80	12.69	94.18
	Euro-V EGR	32.61	27.53	1.08	24.80	12.09	98.11
	Euro-V SCR	31.95	19.07	1.08	24.80	11.85	88.75
	Euro-VI	28.50	1.54	1.08	24.80	10.57	66.49
Truck and trailer/semi-truck (>20-28t)	80ties	27.59	57.66	1.08	24.80	10.26	121.40
	Euro-I	25.82	35.27	1.08	24.80	9.60	96.58
	Euro-II	23.52	34.75	1.08	24.80	8.74	92.90
	Euro-III	23.87	28.84	1.08	24.80	8.88	87.48
	Euro-IV EGR	22.53	22.34	1.08	24.80	8.37	79.13
	Euro-IV SCR	22.30	15.90	1.08	24.80	8.29	72.36
	Euro-V EGR	20.71	20.87	1.08	24.80	7.68	75.15
	Euro-V SCR	20.30	13.64	1.08	24.80	7.53	67.35
	Euro-VI	18.26	0.87	1.08	24.80	6.77	51.78
Truck and trailer/semi-truck (>28-34t)	80ties	36.02	73.94	1.08	24.80	13.39	149.23
	Euro-I	34.22	45.15	1.08	24.80	12.72	117.97
	Euro-II	31.08	43.58	1.08	24.80	11.55	112.10
	Euro-III	31.55	35.89	1.08	24.80	11.73	105.06
	Euro-IV EGR	30.26	27.84	1.08	24.80	11.24	95.23
	Euro-IV SCR	29.94	17.38	1.08	24.80	11.12	84.33
	Euro-V EGR	28.48	23.92	1.08	24.80	10.56	88.85
	Euro-V SCR	27.91	13.35	1.08	24.80	10.35	77.50
	Euro-VI	25.13	0.85	1.08	24.80	9.31	61.18
	80ties	40.53	73.87	1.08	24.80	15.07	155.36
	Euro-I	38.51	51.84	1.08	24.80	14.32	130.56

Value factors by Euronorm classes in €-cent$_{2025}$ / vehicle km, 1% PRTP							
Vehicle category	**Euro standard**	**Operation**			**Pre-processes**		**Total**
		Green-house gases	**Air pollutants Exhaust**	**Air pollutants Abrasion**	**Infra-structure and vehicles**	**Energy supply**	
Truck and trailer/semi-truck (>34-40t)	**Euro-II**	35.57	49.85	1.08	24.80	13.22	124.53
	Euro-III	35.35	40.06	1.08	24.80	13.15	114.45
	Euro-IV EGR	34.07	30.23	1.08	24.80	12.66	102.85
	Euro-IV SCR	33.71	19.50	1.08	24.80	12.52	91.62
	Euro-V EGR	32.49	33.72	1.08	24.80	12.05	104.14
	Euro-V SCR	31.86	19.21	1.08	24.80	11.81	88.77
	Euro-VI	28.51	1.26	1.08	24.80	10.57	66.23

Engines that were in circulation before the introduction of the exhaust emission standard are designated Euro 0 for cars and 80ties for trucks in HBEFA 3.3.
Source: Emission factors for direct emissions are from HBEFA v4.2 and Tremod 6.51; emission factors for indirect emissions are from Tremod 6.51, Ecoinvent 3.3 and Mobitool. Calculations by Walther et al. (2024c), van der Kamp et al. (2024), Anthoff (2025) and own calculations.

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