Methodological Convention 3.1 for the Assessment of Environmental Costs

Value Factors

Version 12/2020

German Environment Agency

Umwelt Bundesamt

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by

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Introductory remarks

The value factors presented in the following chapters are based on the findings of the research project "Methodological Convention 3.0 - Development and Extension of the Methodological Convention for Estimating Environmental Costs" as well as own research of the UBA. Detailed information on the data and methods used can be found in the research reports prepared as part of the research project. These are available on request (Astrid.Matthey@uba.de; Bjoern.Buenger@uba.de).

The value factors shown are average values for emissions in Germany, which can, however, also have an effect abroad. This applies in particular to damage caused by greenhouse gas emissions. Emissions of classical air pollutants and noise cause costs of varying extent depending on the emission context. If the costs are to be estimated for specific local circumstances, the value factors should therefore be adjusted to the respective circumstances where possible. Average values can then only provide an approximation.

The methodological basis for this report is presented in "Methodenkonvention 3.0 zur Ermittlung von Umweltkosten - Methodische Grundlagen" (UBA 2018).

The value factors from the revised chapters 1-4 from "Methodological Convention 3.0 – Cost Rates" were adjusted to the price level of 2020, as were the value factors of the newly added chapters 5-7. All other data (e.g. emission factors, utilisation rates) continue to refer to the 2016 data basis for reasons of consistency. In particular, no adjustment was made to the emission factors, the composition of the vehicle fleet etc.

For an application of the value factors to activities or emissions after 2020, a price adjustment is required. For this purpose, we recommend adjusting the value factors with the consumer price index of the German Federal Statistical Office.

1 Assessment of climate change impacts

1.1 Value factors for carbon dioxide and other greenhouse gas emissions

We recommend using a value factor of 195 €$_{2020}$ / t $CO_{2\ eq}$ for the year 2020 when placing a higher weighting on the welfare of current versus future generations and a value factor of 680 €2020 / t $_{CO2\text{-}eq}$ when equally weighting the welfare of current and future generations.[1] In addition, we recommend a sensitivity analysis with the respective other value.

Table 1: UBA recommendation on climate costs in €$_{2020}$ / t $CO_{2\ eq}$

	Climate costs in €$_{2020}$ / t $CO_{2\ eq}$		
	2020	**2030**	**2050**
1% pure time preference rate	195	215	250
0% pure time preference rate	680	700	765

Source: Own presentation.

- In order to use 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 of the German Federal Statistical Office[2].
- In order to transfer the value factors of carbon dioxide to other greenhouse gases, we recommend using the greenhouse gas potential (Global Warming Potential (GWP), time horizon 100 years). For CH4 (methane), this corresponds to 28 times the value factor of $CO_{2\ eq}$, and for N_2O (laughing gas) to 265 times the value factor of $CO_{2\ eq}$ [3]. The value factors for all of the other greenhouse gases are calculated correspondingly.
- In order to transfer the value factors to greenhouse gas emissions in the aviation sector, we recommend using an emission weighting factor (EGF) of 2. This accounts for the fact that combustion processes develop a higher damage potential at high altitudes[4].

The recommendations in Table1 follow the damage cost approach and are based on the model in Anthoff (2007) with the following specifications[5]:

- Use of equity weighting (Western Europe) to account for damages in different world regions (see Equity Weighting box for explanation);
- Use of 1% trimmed averages as a method for dealing with statistical outliers of the model simulations;

1 Using a pure rate of time preference (PRTP) of 0%, present and future damages are equally weighted. Using a pure time preference rate of 1%, only 74% of the damage incurred by the next generation (in 30 years) is taken into account, and only 55% of the damage incurred by the generation after that (in 60 years). The weighting with PRTP=1% can be used as a proxy for practical policy relevance.

2 https://www-genesis.destatis.de/genesis/online?operation=result&code=61111-0001&deep=true#abreadcrumb

3 Cf. IPCC AR5 (2014)

4 Cf. ifeu / INFRAS / LBST (2016)

5 See also Bachmann (2018)

- Discounting to the year of emission;
- Use of the German consumer price index of the German Federal Statistical Office in order to adjust prices from 2010-2020 (factor 1.13)[6];
- Use of World Bank purchasing power parities for currency conversion from USD into EUR[7].

Background:

New scientific findings on climate damage costs have been published since the publication of the Methodological Convention 2.0. A review of these results shows that damage cost estimates are becoming more robust overall (cf. also IPCC (2014), p. 691). We therefore consider it appropriate to use a pure damage cost approach to derive our recommended cost rate (see also Chapter 3.1 in the volume "Methods" of Methodological Convention 3.0).

The damage costs found in the literature vary considerably. For the purposes of erring on the conservative side, the recommended value factors continue to be based on the FUND damage cost model (version 3.0, Anthoff 2007) used in the Methodological Convention 2.0, the results of which are in the lower range of damage cost estimates in the literature (cf. e.g. Moore and Diaz 2015, Gillingham et al. 2015, who determine significantly higher value factors). The recommended value of 195€$_{2020}$ / t $CO_{2\,eq}$ is close to the value of 182€$_{2020}$ / t CO_2 determined in the IPCC's 5th Assessment Report[8].

Damage cost and abatement cost approach

Regarding climate costs, the damage costs approach is used to estimate the level of damages incurred by society as a result of greenhouse gas emissions and the resulting climate change. In contrast, the abatement cost approach is used to estimate the costs that have to be borne by society in order to mitigate climate change, i.e. to reduce greenhouse gas emissions to an agreed level. Depending on the context and problem, one or the other approach is conceptually the correct approach (see also Chap. 3.1 and 3.2 in the volume "Methods" of Methodological Convention 3.0).

All value factors of the Methodological Convention pursue the first-mentioned goal of assessing the damages in monetary terms that society incurs due to environmental pollution. This goal is best met by the damage cost approach, which is therefore used to determine the value factors of the Methodological Convention, including the climate costs.

On the other hand, it is appropriate to use the abatement cost approach if the quantity of environmental impacts to be avoided (e.g. greenhouse gas emissions) has been politically stipulated and the costs of the measures which help to achieve these reduction goals are to be estimated.

The UBA has advocated using equity weighting to take equal account of the welfare effects on all humans since the first methodological convention in 2007. If the damage for greenhouse gases emitted in Germany is to be estimated, the global damage must therefore be weighted with the respective ratio of average incomes (see box *Equity Weighting*). If the modelling data for the German average income are not available, the modelling data for the average income that comes

6 Destatis (2020)

7 World Bank (2018)

8 IPCC (2014), p. 691, average over all available studies with 1% pure time preference rate and different equity weighting assumptions, discounted to 2020, currency conversion via World Bank purchasing power parities.

closest to the German value are to be used accordingly. In Anthoff's (2007) model, this is the average income for Western Europe. We thus value the damage costs caused by one tonne of $CO_{2\,eq}$ as if they were incurred (entirely) in Western Europe. Differences in income within Western Europe or within Germany are not considered, i.e. the damage is valued as if climate impacts affect poor and rich people in Western Europe or Germany equally.

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 different economic wealth in various regions of the world, comparable damages correspond to different nominal monetary values. If, for example, residential buildings are destroyed by severe 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" in economic terms) as people in richer countries, often even more so, due to the lack of insurance and state subsidies. It is true that it is also nominally cheaper to make good 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.

With equity weighting, the nominal monetary values of the damage 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 €100 per capita, the damage amounts to 1/100 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 50 times less, the nominal damage costs are weighted 50 times higher.

It would not be necessary to use equity weighting when calculating climate costs, if the affected parties were to actually be immediately compensated by the parties causing the damage. However, this is not a realistic assumption. Equity weighting is therefore required, since the valuation of the impacts of climate change is ultimately concerned with quantifying the impacts on the quality of life (the "utility") of the people.

1.2 Value factors for greenhouse gas emissions as a result of land use change

Based on the value factor for greenhouse gas emissions, the greenhouse gas inventory (UBA 2019a) allows for the calculation of costs resulting from land use changes. These land use changes comprise e.g. the conversion of forests into arable land (34,300 €/ha in the year of conversion) or the sealing of land. Conversely, benefits can also be derived, for example from the conversion of arable land into grassland (100€/ha in the year of conversion). These cost and benefits are displayed for a value factor of 195€/ $t_{CO2\,eq}$ in Table 2 and a value factor of 680 €/$t_{CO2\,eq}$ in Table 3. They refer to the year of conversion; in comparison with subsequent years, deviations may occur due to growth processes.

Table 2: **a) Costs (negative sign) and benefits (positive sign) rounded per hectare and year [€ ha^{-1} a^{-1}] in the year of conversion in above and below ground biomass after land use change for the year 2017 at a value factor of 195€/t $CO_{2\ eq.}$**

	Forest	Field	Grassland in the narrower sense	Woody plants	Terrestrial wetlands	Water-bodies	Settle-ments
	Assessment of mean carbon stocks in above- and belowground biomass						
[€ ha^{-1}]	39,100	4,800	4,900	30,900	13,500	0	8,900
	Costs for a change in biomass [€ ha^{-1} a^{-1}]						
Forest		-34,300	-34,200	-8,200	-25,500	-39,100	-30,200
Field	2,500		100	26,100	8,700	-4,800	4,100
Grassland in the narrower sense	2,300	-100		26,000	8,700	-4,900	4,100
Woody plants	1,400	-26,100	-26,000		-17,300	-30,900	-21,900
Terrestrial wetlands	2,500	-8,700	-8,700	17,300		-13,500	-4,600
Waterbodies	2,600	4,800	4,900	30,900	13,500		8,900

Source: Own calculations based on UBA (2019a). Grassland in the narrow sense includes meadows and pastures.

Table 3: b) Costs (negative sign) and benefits (positive sign) rounded per hectare and year [€ ha^{-1} a^{-1}] in the year of conversion in above- and below-ground biomass after land use change for the year 2017 at a value factor of 680€/t $CO_{2\ eq.}$

	Forest	Field	Grassland in the narrower sense	Woody plants	Terrestrial wetlands	Water-bodies	Settle-ments
	Assessment of mean carbon stocks in above- and belowground biomass						
[€ ha^{-1}]	136,300	16,700	17,000	107,600	47,200	0	31,100
	Costs for a change in biomass [€ ha^{-1} a^{-1}]						
Forest		-119,600	-119,300	-28,700	-89,100	-136,300	-105,100
Field	8,600		300	90,900	30,500	-16,700	14,400
Grassland in the narrower sense	8,100	-300		90,600	30,200	-17,000	14,200
Woody plants	4,800	-90,900	-90,600		-60,400	-107,600	-76,500
Terrestrial wetlands	8,700	-30,500	-30,200	60,400		-47,200	-16,100
Waterbodies	9,100	16,700	17,000	107,600	47,200		31,100
Settlements	8,500	-14,400	-14,200	76,500	16,100	-31,100	

Source: Own calculations based on UBA (2019a). Grassland in the narrow sense includes meadows and pastures.

2 Value factors for air pollutants

2.1 Average value factors for air pollutant emissions

For the modelling of air quality and exposure we use the EcoSenseWeb model developed for the EU project NEEDS (New Energy Externalities for Sustainability), Version v1.3 (Preiss et al. 2008), that has already been used in the Methodological Convention 2.0. There are more recent findings for modelling the atmospheric dispersion of emissions with the EMEP model. However, these are not taken account of in the currently available version of EcoSenseWeb and can therefore not be used to assess the value factors.

The health effects of air pollutants were assessed on the basis of current data from the literature (compiled in WHO 2013) and monetary assessment factors were aligned to the greatest possible extent with current EU standards (Holland 2014). Crop failures were assessed on the basis of the response functions in Mills et al. (2007). Where this was not possible, value factors were derived from updated NEEDS data – which we also used to assess building/material damage and biodiversity losses.

In order to allocate the value factors to individual emissions and thus make them usable for applications such as cost-benefit analyses, the environmental costs are calculated as average costs per unit of the pollutant emitted. Further, the values draw on emissions rather than immissions, as it is frequently much easier to determine the emissions from individual installations, projects, legislative proposals etc. than the associated immissions. The relationship between emissions and immissions is modelled as part of the impact pathway approach. This approach is justified by the requirement of the Methodological Convention to provide transferable, average value factors for a wide range of applications.

Table 4 shows the average environmental costs per emitted tonne of the respective pollutant[9] for emissions from "unknown sources" [10] in Germany. These average values can be used for a rough estimate of the damage costs caused by air pollutants if no specific information on the emission sources is available.

Table 45: Average environmental cost of air pollution from emissions from unknown source (in €$_{2020}$ / t emission)

€$_{2020}$/t emission	Value factors for emissions in Germany				
	Health damage	Biodiversity loss	Crop damage	Material damage	Total
Germany total					
$PM_{2.5}$	61,500	0	0	0	61,500
PM_{coarse}	1,000	0	0	0	1,000
PM_{10}	43,300	0	0	0	43,300

[9] The most important air pollutants in this context are particulate matter (PM), nitrogen oxides (NOx), sulphur dioxide (SO2), non-methane volatile organic compounds (NMVOC) and ammonia (NH3).

[10] Unknown sources (unknown height of release) means here that there is no specification regarding the stack height of the respective system. These are therefore average values. Emissions from low sources (installations with low stack heights) have higher costs; those from higher sources have correspondingly lower values.

	Value factors for emissions in Germany				
NO_X	15,200	2,800	900	100	19,000
SO_2	14,300	1,100	-200	600	15,800
NMVOC	1,200	0	1,000	0	2,200
NH_3	22,800	11,000	-100	0	33,700

Assumption: PM_{10} consists of 70% $PM_{2.5}$ and 30% PM_{coarse}. For NO_x and SO_2, the costs represent the damage caused by secondary particulate matter formation. Source: Van der Kamp et al. (2017), own calculations. Note: The price adjustment to 2020 was made on non-rounded values to reduce rounding errors.

These and the following values refer to emissions in the year 2016, given in 2020 prices. In the original sources, the costs are given in €$_{2000}$ or €$_{2005}$. To reflect the present value of the euro, the price level changes in Germany between 2000 or 2005 and 2020 have been taken into account. We used the consumer price index of the German Federal Statistical Office to convert the value factors to €$_{2020}$.[11] Furthermore, it was taken into account that the willingness to pay for avoiding immaterial health damage (pain and suffering) increases with income. To this end, the value factors were corrected for changes of the gross domestic product per capita in Germany between 2005 and 2016 (including the use of an elasticity figure of 0.85, which reflects the assumed increase in willingness to pay with income; a GDP correction to 2020 for consistency reasons was not made)[12].

In the NEEDS project, environmental value factors were also determined for other European countries. From a scientific point of view, however, it is hardly worthwhile to give European average values for value factors from air pollutant emissions. This is due to the fact that there are considerable differences in the factors relevant to valuation between the European countries, primarily in the spatial distribution of the population and the emission sources.

2.2 Differentiated value factors for air pollutant emissions from different sources

As a rule, the lower the emission source and the higher the population density in the vicinity of the emission source, the more serious are the adverse impacts of air pollutant emissions on health. That is why 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. The value factors for the other air pollutants show little variation with regard to the release height and location. For most applications it is therefore sufficient to use average value factors. However, if site-specific valuations are needed or the proportion of particulate matter emissions is relatively high, using differentiated value factors brings a gain in information.

Table 5 shows the value factors for Germany. On the one hand, the values differ according to different release heights for power generation (power stations, release height >100m), industrial power generation (20-100m) and small-scale combustion plants (0-20m). On the other hand, a distinction is made between emissions from large metropolitan and urban areas.

[11] The data are available at https://www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Preise/Verbraucherpreisindizes/Tabellen_/VerbraucherpreiseKategorien.html.

[12] The data can be accessed at http://ec.europa.eu/eurostat/web/national-accounts/data/main-tables.

The values given refer to emissions for the year 2016 and have been converted to $€_{2020}$ using the consumer price index.

Table 67: Value factors for the emission of air pollutants from small combustion plants and combustion processes in industry (in €$_{2020}$ / t emission)

	Damage to health											Material damage	Crop damage	Biodiversity losses
	Power stations	Combustion processes in industry					Small scale combustion facilities							
		Un-known	City		Town		Un-known	City		Town				
Height (in m)	>100		0-20	20-100	0-20	20-100		0-20	20-100	0-20	20-100			
$PM_{2.5}$	33,100	68,300	122,200	69,000	84,700	69,000	64,900	116,300	65,600	80,500	65,600	0	0	0
PM_{coarse}	500	1,200	2,100	1,200	1,500	1,200	1,100	1,900	1,100	1,300	1,100	0	0	0
PM_{10}	23,300	48,200	86,200	48,600	59,700	48,600	45,800	81,900	46,200	56,800	46,200	0	0	0
NO_x	11,600	16,100	16,100	16,100	16,100	16,100	16,600	16,600	16,600	16,600	16,600	140	850	2,750
SO_2	13,400	15,300	15,300	15,300	15,300	15,300	15,500	15,500	15,500	15,500	15,500	640	-170	1,060
NMVOC	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	1,300	0	1,000	0
NH_3	25,000	25,000	25,000	25,000	25,000	25,000	24,800	24,800	24,800	24,800	24,800	0	-190	11,990

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 NO_x and SO_2, the costs only represent the damage caused by secondary particulate matter formation. Source: Van der Kamp et al. (2017) and own calculations.

2.3 Value factors for air pollutants from road traffic

Emissions from road transport are released very close to the ground (release height 0-3m) and are therefore taken up more strongly by the receptors than emissions released at greater heights. This is particularly true for emissions of particulate matter, since the low release heights imply that they are more frequently inhaled by humans and thus have more severe health effects. For this reason, the impacts of these emissions require special attention. In addition, more people are affected by emissions in urban agglomerations with their high population density. The value factors for the different areas therefore have an adjustment factor for the average costs, which reflects the population density of the respective environment (urban, suburban, rural).

Table 8: Value factors for the emission of air pollutants in transport (in €$_{2020}$ / t emission)

	Health damage				Non-health related damage
Surroundings	**Unknown**	**Urban**	**Suburban**	**Rural**	
$PM_{2.5}$	62,900	255,300	73,600	43,200	0
PM_{coarse}	1,000	4,900	1,200	600	0
PM_{10}	7,200	30,000	8,500	4,900	0
NO_x	15,800	15,800	15,800	15,800	3,700
SO_2	14,900	14,900	14,900	14,900	1,500
NMVOC	1,200	1,200	1,200	1,200	1,000
NH_3	24,200	24,200	24,200	24,200	10,900

The categories Urban, Suburban and Rural differ according to population density (Urban > 1,500, 300< Suburban <1,500, Rural < 300), assumption: PM_{10} consists of 10% $PM_{2.5}$ and 90% PM_{coarse}. For NO_x and SO_2, the costs only represent the damage caused by secondary particulate matter formation.

Note: The price adjustment to 2020 was made based on non-rounded values to reduce rounding errors.

Source: Van der Kamp et al. (2017) and own calculations.

3 Value factors for power and heat generation

3.1 Value factors for power generation

To assess the environmental costs of power generation in Germany, emission factors for the various power generation technologies are required. The German Environment Agency regularly publishes emission factors in the unit grams per kilowatt-hour of electricity (kWh_{el}, i.e. based on the unit of the electrical power produced) for fossil and renewable power generation technologies.

Furthermore, the emission factors are divided into direct and indirect emissions. Direct emissions refer to emissions that arise in the context of power generation, i.e. during the operating phase of the life cycle of the individual technologies. Indirect emissions arise during the other phases of the life cycle (construction, maintenance, decommissioning).

Using these emission factors and the value factors per tonne of emitted pollutants presented in Chapters 1 and 2, it is possible to calculate the value factors for various power generation technologies. By comparing the different value factors, it is possible, inter alia, to assess the environmental damage avoided by generating power from renewable sources. However, it should be borne in mind that the value factors merely take account of greenhouse gases and air pollutants. Other environmental impacts, such as the impairment of ecosystems or land use changes, are only partially taken into account in the value factors, or not at all.

There are basically two possible methods to assess the value factors. For a differentiated analysis, on the one hand, information and assumptions on the locations of the power generation facilities in Germany as well as the respective air pollutants emitted are necessary. For an analysis at the national level, on the other hand, information on overall emissions is sufficient. As a result, the calculations are easier to follow and also easier to update if new emission factors become available. The deviations from the above-mentioned differentiated method tend to be small and have no influence on the qualitative conclusions. Therefore, the assessment of the value factors below is based on the overall emissions, with both, direct and indirect emissions being assessed with the value factors for Germany (for the respective release height and environment). If, in individual cases, site-specific environmental damage per technology or energy source is to be calculated, we recommend using the differentiated value factors from Chapters 1 and 2.

Table 9: Value factors for electricity generation in Germany including upstream chains in €-cent$_{2020}$ / kWh$_{el}$

Power generation from	Air pollutants	Greenhouse gases (195 €/tCO_2 eq)	Greenhouse gases (680 €/tCO_2 eq)	Total environmental costs (195€/tCO_2 eq)	Total environmental costs (680 €/tCO_2 eq)
	Fossil energy sources				
Lignite	2.05	20.65	71.56	22.70	73.61
Hard coal	1.68	18.82	66.91	20.50	66.91
Natural gas	0.87	8.51	29.48	9.38	30.34
Oil	5.18	16.56	57.41	21.74	62.60
	Renewable energy sources				
Hydropower	0.06	0.26	0.91	0.33	0.97
Wind energy*	0.11	0.20	0.68	0.30	0.79
Photovoltaics	0.43	1.35	4.67	1.78	5.09
Biomass**	3.94	4.84	16.77	8.78	20.71

* Average value from onshore and offshore wind energy weighted according to generation shares;
** Average value weighted by generation shares for gaseous, liquid and solid biomass.
Source: Own representation based on Bachmann and van der Kamp (2018) and own calculations.

The environmental costs of the electricity mix in Germany for 2019 are approximately 12.0 €-cent / kWh$_{el}$ (38.1 €-cent / kWh$_{el}$ at a cost of 680 €/t $CO_{2\ eq}$), again based on the 2016 emission factors.

When estimating the environmental costs of nuclear power, there is the problem that the results in the literature show wide ranges of values which can be attributed, inter alia, to difficulties with the valuation of nuclear incidents and dealing with contaminated waste. We therefore recommend that the emission factors for the technology with the highest environmental costs, in this case lignite, should be used as a proxy to value nuclear energy. This approach was already used in the Methodological Convention 3.0.[13]

3.2 Value factors for heat generation

The approach for assessing the environmental costs of heat generation is similar to that for power generation. As for power generation, the German Environment Agency determines the emission factors for direct and indirect emissions for each energy source. To determine the value factors, these are subsequently weighted with the Germany-wide average value factors (for the respective release height and environment). If a site-specific assessment is required, the differentiated value factors from Chapters 1 and 2 should be used.

[13] For more details on this procedure, see "Methodological convention 3.0 - Methods" Chapter 2.5.4. This recommendation was also followed in determining the above-mentioned environmental cost rate for the 2019 electricity mix in Germany.

Table 10: Value factors for heat generation of the households in Germany in €-cent$_{2020}$/ kWh$_{\text{final energy}}$

Heat generation using	Air pollutants	Greenhouse gases (195 €/t$CO_{2\,eq}$)	Greenhouse gases (680 €/t$CO_{2\,eq}$)	Total environmental costs (195 €/t$CO_{2\,eq}$)	Total environmental costs (680 €/t$CO_{2\,eq}$)
	Fossil energy sources				
Heating oil	0.86	6.27	21.74	7.14	22.59
Natural gas	0.41	4.90	17.00	5.32	17.41
Lignite (briquette)	4.18	8.43	29.22	12.61	33.39
District heating with network losses*	1.37	6.25	21.66	7.62	23.05
Electricity heating with grid losses**	1.75	11.97	41.47	13.71	43.22
	Renewable energy sources				
Solar thermal	0.21	0.24	0.83	0.45	1.03
Surface geothermal energy	0.74	3.95	13.70	4.69	14.43
Deep geothermal energy	0.01	0.01	0.04	0.02	0.05
Biomass***	2.24	0.66	2.28	2.90	4.54

* 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 Bachmann / van der Kamp (2018) and own calculations.

4 Value factors for passenger and freight transport in Germany

The assessment of the environmental costs of passenger and freight transport in Germany is divided into two parts. In a first step, the emissions from the operation of the various vehicle types, which arise from combustion of fuels, abrasion and dust turbulence are assessed. Subsequently, the emissions from the other phases of the life cycle are estimated, e.g. construction, maintenance and waste management as well as fuel supply logistics.

In addition to air pollutant emissions and greenhouse gas emissions, transport causes noise and further adverse impacts on nature and landscape, primarily due to landscape fragmentation and land sealing caused by the necessary underlying infrastructure. Cost estimates exist for some of these aspects as well, and must be added to the emission-related costs. The approach and the resulting transport-related value factors are described below.

4.1 Assumptions for the emission calculations

Emission-induced adverse impacts on the environment and health are more pronounced in cities than in rural areas or on motorways due to variations in population densities. Therefore, in order to estimate transport-related value factors (e.g. costs per vehicle kilometre), it is necessary to assess the respective emissions (e.g. per vehicle kilometre) and to break down the proportion of mileage in urban areas, rural areas and on motorways. The percentages of mileage (Table 9) correspond to the data from the TREMOD model (Transport Emission Model) used by the German Environment Agency.

Table 1112: Breakdown of mileage in road transport (urban, rural, motorway) by vehicle category

Vehicle type	Urban	Rural	Motorway
Cars	26%	41%	33%
Light commercial vehicles (LCV)	44%	27%	29%
Heavy goods vehicles (HGV)	14%	25%	61%
Motorcycles	39%	52%	9%
Public buses	57%	37%	6%
Coaches	9%	58%	34%

Source: HBEFA 3.3.

Emission factors from the "Handbuch für Emissionsfaktoren des Straßenverkehrs" (Handbook of Road Transport Emission Factors) (HBEFA 3.3) for the year 2016 were used to assess the emissions for the operating phase of vehicles in road transport. The HBEFA provides emission factors in grams per vehicle kilometre for the air pollutants CO, NH_3, NMVOC, NO_X, $PPM_{2.5}$ and SO_2 as well as for the greenhouse gases CH_4, CO_2 and N_2O.

The emission factors for direct emissions, which are used to determine the value factors for passenger and freight trains, are taken from the TREMOD model.

Furthermore, the calculations of the value factors for emissions from road and rail transport in Germany are carried out for the average fleet of the various vehicle types and for the Euro standard classes (Euro 1 to Euro 6 for cars and Euro I to Euro VI for trucks[14]) of the vehicle types and their subclasses.

In the aviation sector, for most of the distance covered, the combustion process takes place at high altitudes, thereby effecting a climate impact that goes beyond the mere emission of greenhouse gases. To reflect this additional impact, the value factors for the greenhouse gases emitted during flight operations are multiplied by a factor of 2 (see the corresponding recommendation in the chapter on greenhouse gas emissions).

Costs of the construction, maintenance and disposal phase of the vehicles

To assess the costs throughout these phases, data from the life cycle inventory ecoinvent 3.3 were used. The emission factors are based on the data provided in Spielmann et al. (2007) on overall emissions and total mileage of the individual vehicle types. [15]

Fuel supply

Emissions from fuel supply were calculated using the emission factors from TREMOD. [16]

4.2 Value factors for damage caused by land use and fragmentation

To assess the environmental costs induced by loss and fragmentation of natural habitats, we rely on calculations from the study "External Effects of Transport 2015" which was conducted by the Swiss Federal Office for Spatial Development. The factors from this study are displayed in Table10.

A restoration cost approach is used to estimate the value factors: in case of habitat losses, the costs for (virtually) restoring lost biotope or ecosystem areas are drawn upon, whereas in case of habitat fragmentation, the costs for (virtually) constructing defragmentation structures provide the basis. [17]

Motorways, federal highways, state roads and district roads were considered for road transport. Rail transport was based on train routes. The land use for air transport was inferred from the statistic "Flächenerhebung nach Art der tatsächlichen Nutzung" (Area survey by type of actual use) of the German Federal Statistical Office[18].

Table 1314: Figures for environmental costs of road transport due to land use and fragmentation, in €-cent$_{2020}$ per vehicle kilometre

Vehicle category	Costs due to land use and fragmentation [€-cent$_{2020}$/vehicle km]
Car	0.36
Bus	0.85

[14] In addition to the Euro standard classes 1 to 6 and I to VI, the pollutant values for engines used before the introduction of the exhaust emission standard were also considered. In the HBEFA 3.3, these vehicles are indicated as Euro 0 for cars and 80ties for trucks.

[15] Spielmann et al. (2007) indicate which processes were considered: "Included processes: The inventory includes processes of material, energy and water use in vehicle manufacturing. Rail and road transport of materials is accounted for. Plant infrastructure is included, addressing issues such as land use, building, road and parking construction."

[16] To calculate the emissions from fuel supply, the processes "market for diesel" and "market for petrol" from the ecoinvent database were used. These processes already include all transport routes of the fuels.

[17] Cf. INFRAS/Ecoplan (2018), p. 79 in conjunction with Ecoplan/INFRAS (2014), p. 18.

[18] Cf. Destatis (2017a).

Vehicle category	Costs due to land use and fragmentation [€-cent$_{2020}$/vehicle km]
Small motorcyle	0.12
Motorcycle	0.16
Passenger train, local transport	41.75
Passenger train, long-distance	62.63
Passenger air transport (short and medium haul; <2,000 km)	9.01
Passenger air transport (Long haul; > 2,000 km)	16.54
Light commercial vehicles (LCV)	0.38
Heavy goods vehicle (HGV) <7.5t	0.43
HGV 7.5-14t	0.79
HGV 14-28t	0.85
HGV: Trailer 28-40t	1.07
Freight train	130.49
Freight air transport	27.28

The value factors for air transport proportionally account for belly freight.
Source: INFRAS (2018), Umweltkosten Verkehr, Excel tool and own calculations.

4.3 Value factors for noise

In densely populated and congested Germany, broad sections of the population are affected by noise. Many people are exposed to high levels of noise pollution, which adversely affect their health and reduce their quality of life. Road, rail and air traffic represent the main sources of noise pollution. In the following we will derive value factors for traffic noise. When establishing these value factors, even greater attention is to be paid to the respective conditions when assessing the effects of noise on human health (noise characteristics, distance from the noise source, time of day, population density, etc.) than is the case for emissions of air pollutants.

The health costs caused by 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 cost estimates provided in Table11 can, for example, be used to monetise a change in the noise situation resulting from noise reduction measures. It should be borne in mind that these are average values - for a more accurate assessment of the values, on-site noise measurements are necessary.

Table 1516: Cost functions for noise effects based on L_{DEN} values

	Cost functions by category (EUR/person, a)												Total costs (EUR/person, a)		
	Intangible costs - YLD			**Intangible costs - YLL**			**Costs healthcare system**			**Costs production losses**			**All categories**		
dB(A)	**Road**	**Rail**	**Air**	**Road**	**Rail**	**Air**	**Road**	**Rail**	**Air**	**Road**	**Rail**	**Air**	**Road**	**Rail**	**Air**
Overall result for nuisance (excluding self-reported sleep disturbances)															
35-39	0	0	0										0	0	0
40-44	0	0	0										0	0	0
45-49	29.46	9.40	30.95										29.46	9.40	30.95
50-54	59.20	20.71	85.96										59.2	20.71	85.96
55-59	98.60	40.81	164.14										98.60	40.81	164.14
60-64	157.05	76.60	264.63										157.05	76.60	264.63
65-69	243.95	134.93	386.56										243.95	134.93	386.56
70-74	368.66	222.72	529.03										368.66	222.72	529.03
>= 75	540.56	346.83	691.18										540.56	346.83	691.18
Overall results on physical health															
45-49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50-54	0.12	0.08	0.05	0.23	0.19	0.18	0.99	0.12	0.88	0.04	0.01	0.02	1.38	0.40	1.14
55-59	0.56	0.40	0.31	1.47	1.16	1.11	3.88	0.56	3.25	0.19	0.04	0.09	6.10	2.16	4.76
60-64	1.33	0.98	0.96	3.73	2.89	3.36	7.80	1.70	6.88	0.44	0.11	0.33	13.3	5.68	11.52
65-69	2.40	1.85	2.34	6.07	4.70	7.48	12.79	3.92	13.34	0.75	0.23	0.97	22.01	10.70	24.12
70-74	3.64	2.91	4.23	8.46	6.56	13.03	18.44	6.77	21.83	1.08	0.39	1.94	31.62	16.64	41.02

	Cost functions by category (EUR/person, a)												Total costs (EUR/person, a)		
>= 75	4.89	3.96	6.13	10.85	8.42	18.57	24.08	9.62	30.32	1.42	0.55	2.90	41.24	22.57	57.93
Overall results for adverse effects on cognitive and mental health															
45-49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50-54	1.53	1.51	1.11	0.17	0.16	0	0.22	0.21	0	0.15	0.15	0	2.06	2.02	1.11
55-59	9.08	8.98	7.01	0.81	0.77	0	1.05	1.00	0	0.74	0.69	0	11.67	11.45	7.01
60-64	21.33	21.15	18.00	1.45	1.38	0.15	1.88	1.80	0.19	1.32	1.25	0.13	25.99	25.58	18.46
65-69	33.6	33.34	30.6	2.08	1.99	0.92	2.73	2.59	1.20	1.90	1.80	0.83	40.31	39.72	33.55
70-74	45.86	45.52	44.78	2.73	2.60	2.31	3.56	3.38	3.01	2.47	2.36	2.10	54.63	53.86	52.20
>= 75	58.13	57.70	58.97	3.37	3.21	3.71	4.39	4.18	4.82	3.05	2.91	3.36	68.94	67.99	70.85
Overall results across all end points (excluding self-reported sleep disturbances)															
35-39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40-44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45-49	29.46	9.40	30.95	0	0	0	0	0	0	0	0	0	29.46	9.40	30.95
50-54	60.85	22.31	87.11	0.40	0.35	0.18	1.21	0.32	0.88	0.19	0.15	0.02	62.65	23.13	88.20
55-59	108.24	50.2	171.45	2.29	1.93	1.11	4.93	1.56	3.25	0.93	0.74	0.09	116.38	54.42	175.9
60-64	179.73	98.74	283.58	5.18	4.26	3.51	9.69	3.50	7.07	1.76	1.36	0.45	196.34	107.85	294.61
65-69	279.94	170.13	419.48	8.16	6.69	8.39	15.52	6.51	14.54	2.64	2.03	1.80	306.27	185.35	444.22
70-74	418.16	271.15	578.04	11.19	9.16	15.34	22.00	10.15	24.84	3.56	2.75	4.03	454.91	293.21	622.25
>= 75	603.57	408.49	756.28	14.22	11.64	22.28	28.47	13.80	35.14	4.49	3.45	6.25	650.74	437.38	819.95

L_{DEN} = Day-Evening-Night Noise Level; Source: Sachstandspapier Lärm (research report on noise); own calculations.

Furthermore, statements regarding the costs inflicted by noise pollution from traffic on the German population can be made. To this end, the findings of the noise mapping according to the EU Environmental Noise Directive are used. The findings of the noise mapping for the year 2017 are illustrated in Table 12. The table discloses the number of people that were affected by noise from each mode of transport in the reference year 2016. These figures were blended with the cost functions given in Table 11. The findings are also shown in Table 12.

Table 1718: Traffic noise pollution suffered by the population in pursuance of the EU Environmental Noise Directive and the resulting healthcare costs (reference year of mapping: 2016)

	*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	3,961,400	2,409,200	1,649,300	632,300	65,200
Number of people affected by rail traffic noise	3,787,300	1,645,500	679,600	231,600	92,600
Number of people affected by air traffic noise	606,400	205,800	30,700	3,700	0
Healthcare costs due to road traffic noise [€]	461,018,066	473,028,062	505,122,947	287,637,399	42,428,474
Healthcare costs due to rail traffic noise [€]	206,101,230	177,464,312	125,963,221	67,906,938	40,501,815
Healthcare costs due to air traffic noise [€]	106,667,973	60,630,396	13,637,510	2,302,322	0

Source: Noise mapping 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.

Consequently, healthcare costs totaling €$_{2020}$ 1.77 billion were incurred in Germany due to road traffic noise, €$_{2020}$ 618 million due to rail traffic noise and €$_{2020}$ 183 million due to air traffic noise.

4.4 Value factors for transport-related activities

By linking the emission factors for the various vehicle categories, differentiating between urban areas, rural areas and motorways (according to the distribution shown above) as well as between operating and other life cycle phases, the value factors for transport in €-cents$_{2020}$ per vehicle kilometre driven are computed, as shown in Table13a and b.

It is true that mileage-related noise value factors (in € per vehicle kilometre, per passenger kilometre or per tonne kilometre) can be calculated as pure levy quotients, i.e. existing noise pollution or the corresponding costs can be divided by the mileage, e.g. the vehicle kilometres (vehicle km) relating to this. Thus, as an example, a noise-related toll value factor can be derived, which could then be charged for each kilometre driven. However, this value factor is ill-suited to monetise the noise effects of a specific mileage-related measures or developments in the transport sector. The construction of a bypass road, for example, will normally result in an increase in vehicle kilometres, while at the same time reducing noise pollution. Likewise, an overall decline in annual traffic (in vehicle km) in Germany does not necessarily imply lower levels of noise pollution, as traffic may, for example, decrease in sparsely populated areas while at the same time 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 of Methodological Convention 3.1.[19] However, in order to emphasize that traffic-related noise does induce environmental, the corresponding columns in the tables are marked with asterisks (***).

Table 1920: a) Environmental costs per vehicle kilometre (average all routes) for different vehicle types in Germany at a value factor of 195€/t $CO_{2\ eq}$, in €-cent$_{2020}$ / vehicle kilometre

		Operation				Pre-processes		Land consu-mption and fragme-ntation	Total
Vehicle category	Emiss-ion con-cept	Green-house gases	Air pollu-tants Exhaust	Air pollu-tants Abra-sion	Noise	Infra-structure and vehicles	Energy supply		
Car	Petrol	3.01	0.32	0.03	***	2.22	1.01	0.36	6.95
Car	Diesel	2.58	1.57	0.03	***	2.53	1.04	0.36	8.11
Car	Electric	0	0	0.03	***	3.38	2.82	0.36	6.58
Small motorcycle	Petrol	1.57	0.75	0.01	***	2.22	0.64	0.12	5.30
Motorcycle	Petrol	1.96	0.57	0.01	***	2.39	1.08	0.16	6.16
Public bus	Diesel	20.66	11.34	0.16	***	5.18	6.39	0.85	44.58
Coach	Diesel	13.84	9.11	0.09	***	6.50	4.80	0.85	35.19

[19] 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-impact functions and, if applicable, the exposure-related noise cost rates of the Methodological Convention.

Vehicle category	Emission concept	Operation: Greenhouse gases	Operation: Air pollutants Exhaust	Operation: Air pollutants Abrasion	Operation: Noise	Pre-processes: Infrastructure and vehicles	Pre-processes: Energy supply	Land consumption and fragmentation	Total
Passenger train, long-distance	Electric	0	0	0.68	***	216.51	238.12	62.63	517.94
Passenger train, local transport	Weighted Av.	19.19	21.61	0.35	***	63.54	97.09	41.75	243.53
Passenger air transport, short and medium haul		504.61	254.34	0	***	21.6	151.84	9.01	941.40
Passenger air transport, long-haul		836.97	458.06	0	***	24.2	251.97	16.54	1,587.74
LCV	Petrol	3.09	0.63	0.03	***	1.79	1.19	0.38	7.10
LCV	Diesel	2.58	2.10	0.03	***	1.95	1.28	0.38	8.32
LCV	Electric	0	0	0.03	***	3.03	5.19	0.38	8.63
HGV <7.5t	Diesel	6.21	2.41	0.07	***	2.60	3.02	0.43	14.74
HGV 7.5-14t	Diesel	8.50	2.74	0.07	***	3.86	3.59	0.79	19.55
HGV 14-28t	Diesel	11.55	3.42	0.07	***	5.28	4.70	0.85	25.88
HGV: Trailer 28-40t	Diesel	14.65	3.37	0.07	***	7.44	5.38	1.07	31.99
Freight train	Weighted av.	18.16	25.59	0.81	***	297.42	216.00	130.49	688.47
Freight-air transport		1,078.24	612.89	0	***	23.85	323.82	27.28	2,066.09
Motor vessels (inland waterways transport)		551.75	934.75	0	***	634.73	152.72	0	2,273.94
Watercraft assemblies (inland waterways transport)		1,003.66	1,718.70	0	***	1,164.32	300.02	0	4,186.68

Weighted Av. = weighted average electric/diesel.
The value factors for air transport, proportionally account for belly freight.
Source: Emission factors for direct emissions are from HBEFA v3.3 and Tremod; emission factors for indirect emissions are from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS as part of the research project and own calculations.

Table 21: b) Environmental costs per vehicle kilometre (average of all routes) for different vehicle types in Germany at a value factor of 680€/t $CO_{2\ eq}$, in €-cent$_{2020}$ / vehicle kilometre

		Operation				Pre-processes		Land consumption and fragmentation	Total
Vehicle category	Emission concept	Greenhouse gases	Air pollutants - Exhaust	Air pollutants Abrasion	Noise	Infrastructure and vehicles	Energy supply		
Car	Petrol	10.45	0.32	0.03	***	5.14	2.68	0.36	18.97
Car	Diesel	8.95	1.57	0.03	***	5.77	2.80	0.36	19.47
Car	Electric	0	0	0.03	***	7.35	8.85	0.36	16.58
Small motorcycle	Petrol	5.44	0.75	0.01	***	4.68	1.46	0.12	12.45
Motorcycle	Petrol	6.81	0.56	0.01	***	6.35	2.46	0.16	16.35
Public bus	Diesel	71.58	11.34	0.16	***	12.84	17.20	0.85	113.96
Coach	Diesel	47.95	9.11	0.09	***	15.87	12.92	0.85	86.80
Passenger train, long-distance	Electric	0	0	0.69	***	496.56	722.51	62.63	1,282.39
Passenger train, local transport	Weighted Av.	66.52	21.61	0.35	***	145.73	290.95	41.76	566.92
Passenger air transport, short and medium haul		1,748.79	254.34	0	***	55.48	412.86	9.01	2,480.48
Passenger air transport, long-haul		2,900.65	458.06	0	***	62.14	685.15	16.54	4,122.54
LCV	Petrol	10.69	0.63	0.03	***	4.10	3.14	0.38	18.96
LCV	Diesel	8.95	2.09	0.03	***	4.42	3.43	0.38	19.30
LCV	Electric	0	0	0.03	***	6.52	12.99	0.38	19.91
HGV <7.5t	Diesel	21.5	2.41	0.07	***	5.90	6.44	0.43	36.76
HGV 7.5-14t	Diesel	29.45	2.74	0.07	***	8.82	8.27	0.78	50.14
HGV 14-28t	Diesel	40.02	3.42	0.07	***	11.97	11.07	0.86	67.41
HGV: Trailer 28-40t	Diesel	50.75	3.37	0.07	***	16.89	13.45	1.07	85.61
Freight train	Weighted Av.	62.96	25.58	0.81	***	686.87	650.68	130.49	1,557.39
Freight-air transport		3,736.82	612.88	0	***	61.25	881.86	27.28	5,320.10

Vehicle category	Emiss-ion con-cept	Operation				Pre-processes		Land consu-mption and fragme-ntation	Total
		Green-house gases	Air pollu-tants - Exhaust	Air pollu-tants Abra-sion	Noise	Infra-structure and vehicles	Energy supply		
Motor vessels (inland waterways transport)		**1,912.15**	**934.75**	**0**	*******	**641.05**	**388.05**	**0**	**3,876.00**
Water craft assemblies (inland waterways transport)		**3,478.33**	**1,718.70**	**0**	*******	**1,175.92**	**762.32**	**0**	**7,135.27**

Weighted Av. = weighted average electric/diesel.
The value factors for air transport, proportionally account for belly freight.
Source: Emission factors for direct emissions are from HBEFA v3.3 and Tremod; emission factors for indirect emissions are from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS as part of the research project and own calculations.

Table 22: a) Environmental costs per vehicle kilometre (motorway) for different vehicle types in Germany at a value factor of 195€/t $CO_{2\ eq}$ in €-cent$_{2020}$ / vehicle kilometre

Vehicle - category	Emission concept	Operation: Greenhouse gases	Operation: Air pollutants Exhaust	Operation: Air pollutants Abrasion	Operation: Noise	Pre-processes: Infrastructure and vehicles	Pre-processes: Energy supply	Land consumption and fragmentation	Total
Car	Petrol	3.45	0.41	0.02	***	2.22	1.01	0.36	7.47
Car	Diesel	2.64	1.95	0.02	***	2.53	1.04	0.36	8.53
Car	Electric	0	0	0.02	***	3.38	2.82	0.36	6.57
Small motorcycle	Petrol	2.41	1.14	0.01	***	2.22	0.64	0.12	6.53
Motorcycle	Petrol	2.53	1.36	0.01	***	2.39	1.08	0.16	7.52
Public bus	Diesel	13.91	6.11	0.04	***	5.18	6.39	0.85	32.49
Coach	Diesel	13.20	7.89	0.04	***	6.50	4.80	0.85	33.28
LCV	Petrol	3.23	0.73	0.02	***	1.79	1.19	0.38	7.33
LCV	Diesel	2.64	3.04	0.02	***	1.95	1.28	0.38	9.31
LCV	Electric	0	0	0.02	***	3.03	5.19	0.38	8.62
HGV <7.5t	Diesel	6.39	2.35	0.04	***	2.60	3.02	0.43	14.83
HGV 7.5-14t	Diesel	8.62	2.55	0.04	***	3.86	3.59	0.79	19.45
HGV 14-28t	Diesel	11.39	2.65	0.04	***	5.28	4.70	0.85	24.92
HGV: Trailer 28-40t	Diesel	14.16	2.86	0.04	***	7.44	5.38	1.07	30.96

Source: Emission factors for direct emissions are from HBEFA v3.3 and Tremod; emission factors for indirect emissions are from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS as part of the research project.

Table 23: b) Environmental costs per vehicle kilometre (motorway) for different vehicle types in Germany at a value factor of 680€/t $CO_{2\ eq}$, in €-cent$_{2020}$ / vehicle kilometre

Vehicle - category	Emiss-ion con-cept	Operation				Pre-processes		Land consu-mption and fragme-ntation	Total
		Green-house gases	Air pollu-tants Exhaust	Air pollu-tants Abra-sion	Noise	Infra-structure and vehicles	Energy supply		
Car	Petrol	11.95	0.41	0.02	***	5.14	2.68	0.36	20.55
Car	Diesel	9.13	1.95	0.02	***	5.77	2.80	0.36	20.03
Car	Electric	0	0	0.02	***	7.35	8.85	0.36	16.57
Small motorcycle	Petrol	8.34	1.13	0.01	***	4.68	1.46	0.12	15.74
Motorcycle	Petrol	8.76	1.36	0.01	***	6.35	2.46	0.16	19.10
Public bus	Diesel	48.21	6.11	0.04	***	12.84	17.20	0.85	85.24
Coach	Diesel	45.76	7.89	0.04	***	15.87	12.92	0.85	83.34
LCV	Petrol	11.21	0.73	0.02	***	4.10	3.14	0.38	19.58
LCV	Diesel	9.13	3.05	0.02	***	4.42	3.43	0.38	20.43
LCV	Electric	0	0	0.02	***	6.52	12.99	0.38	19.91
HGV <7.5t	Diesel	22.17	2.34	0.04	***	5.90	6.44	0.43	37.32
HGV 7.5-14t	Diesel	29.84	2.55	0.04	***	8.82	8.27	0.78	50.32
HGV 14-28t	Diesel	39.45	2.65	0.04	***	11.97	11.07	0.86	66.05
HGV: Trailer 28-40t	Diesel	49.06	2.86	0.04	***	16.89	13.45	1.07	83.38

Source: Emission factors of direct emissions are from HBEFA v3.3 and Tremod; emission factors of indirect emissions are from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS as part of the research project.

Table 24: a) Environmental costs per vehicle kilometre (extra-urban) for different vehicle types in Germany at a value factor of 195€/t $CO_{2\ eq}$ in €-cent$_{2020}$ / vehicle kilometre

Vehicle category	Emissions concept	Operation: Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Pre-processes: Infrastructure and vehicles	Energy supply	Land consumption and fragmentation	Total
Car	Petrol	2.53	0.29	0.02	***	2.22	1.01	0.36	6.43
Car	Diesel	2.23	1.27	0.02	***	2.53	1.04	0.36	7.46
Car	Electric	0	0	0.02	***	3.38	2.82	0.36	6.57
Small motorcycle	Petrol	1.51	0.72	0	***	2.22	0.64	0.12	5.20
Motorcycle	Petrol	1.83	0.54	0	***	2.39	1.08	0.16	5.99
Public bus	Diesel	17.89	8.00	0.06	***	5.18	6.39	0.85	38.38
Coach	Diesel	13.28	8.52	0.06	***	6.50	4.80	0.85	34.01
Passenger train, long-distance	Electric	0	0	0.68	***	216.51	238.12	62.63	517.94
Passenger train, local transport	Weighted. Av.	19.19	21.38	0.24	***	63.54	97.09	41.75	243.20
LCV	Petrol	2.66	0.56	0.01	***	1.79	1.19	0.38	6.58
LCV	Diesel	2.23	1.82	0.01	***	1.95	1.28	0.38	7.67
LCV	Electric	0	0	0.01	***	3.03	5.19	0.38	8.61
HGV < 7.5t	Diesel	5.79	2.21	0.05	***	2.60	3.02	0.43	14.10
HGV 7.5-14t	Diesel	8.00	2.47	0.05	***	3.86	3.59	0.79	18.77
HGV 14-28t	Diesel	11.22	3.41	0.05	***	5.28	4.70	0.85	25.52
HGV: Trailer 28-40t	Diesel	14.58	3.50	0.05	***	7.44	5.38	1.07	32.02
Freight train	Weighted Av.	18.16	25.19	0.55	***	297.42	216.00	130.49	687.81

Weighted Av. = weighted average electric/diesel.
Source: Emission factors for direct emissions are from HBEFA v3.3 and Tremod; emission factors for indirect emissions are from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS as part of the research project.

Table 25: b) Environmental costs per vehicle kilometre (rural) for different vehicle types in Germany at a value factor of 680€/t $CO_{2\ eq}$ in €-cent$_{2020}$ / vehicle kilometre

Vehicle category	Emission concept	Operation: Greenhouse gases	Operation: Air pollutants Exhaust	Operation: Air pollutants Abrasion	Operation: Noise	Pre-processes: Infrastructure and vehicles	Pre-processes: Energy supply	Land consumption and fragmentation	Total
Car	Petrol	8.76	0.30	0.02	***	5.14	2.68	0.36	17.25
Car	Diesel	7.75	1.27	0.02	***	5.77	2.80	0.36	17.96
Car	Electric	0	0	0.02	***	7.35	8.85	0.36	16.57
Small motorcycle	Petrol	5.23	0.71	0	***	4.68	1.46	0.12	12.21
Motorcycle	Petrol	6.34	0.54	0	***	6.35	2.46	0.16	15.86
Public bus	Diesel	62.01	8.00	0.06	***	12.84	17.20	0.85	100.95
Coach	Diesel	46.02	8.52	0.06	***	15.87	12.92	0.85	84.24
Passenger train, long-distance	Electric	0	0	0,46	***	496.56	722.51	62.63	1,282.17
Passenger train, local transport	Weighted Av.	66.52	21.38	0.24	***	145.73	290.95	41.76	566.57
LCV	Petrol	9.20	0.56	0.02	***	4.10	3.14	0.38	17.39
LCV	Diesel	7.75	1.82	0.02	***	4.42	3.43	0.38	17.82
LCV	Electric	0	0	0.02	***	6.52	12.99	0.38	19.90
HGV < 7.5t	Diesel	20.08	2.21	0.05	***	5.90	6.44	0.43	35.10
HGV 7.5-14t	Diesel	27.73	2.47	0.05	***	8.82	8.27	0.78	48.13
HGV 14-28t	Diesel	38.91	3.41	0.05	***	11.97	11.07	0.86	66.27
HGV: Trailer 28-40t	Diesel	50.53	3.49	0.05	***	16.89	13.45	1.07	85.49
Freight train	Weighted Av.	62.96	25.19	0.55	***	686.87	650.68	130.49	1.556.73

Weighted Av. = weighted average electric/diesel.
Source: Emission factors for direct emissions are from HBEFA v3.3 and Tremod; emission factors for indirect emissions are from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS as part of the research project.

Table 26: a) Environmental costs per vehicle kilometre (urban) for different vehicle types in Germany at a value factor of 195€/t $CO_{2\ eq}$ in €-cent$_{2020}$ / vehicle kilometre

Vehicle category	Emiss-ion con-cept	Operation: Green-house gases	Operation: Air pollu-tants Exhaust	Operation: Air pollu-tants Abra-sion	Operation: Noise	Pre-processes: Infra-structure and vehicles	Pre-processes: Energy supply	Land consu-mption and fragme-ntation	Total
Car	Petrol	3.22	0.27	0.11	***	2.22	1.01	0.36	7.19
Car	Diesel	2.97	1.68	0.11	***	2.53	1.04	0.36	8.68
Car	Electric	0	0	0.11	***	3.38	2.82	0.36	6.66
Small motorcycle	Petrol	1.42	0.68	0.03	***	2.22	0.64	0.12	5.12
Motorcycle	Petrol	2.00	0.38	0.03	***	2.39	1.08	0.16	6.04
Public bus	Diesel	23.02	14.63	0.86	***	5.18	6.39	0.85	50.93
Coach	Diesel	19.07	17.75	0.86	***	6.50	4.80	0.85	49.84
Passenger train, long-distance	Electric	0	0	2.85	***	216.51	238.12	62.63	520.11
Passenger train, local transport	Weigh-ted Av.	19.19	23.93	1.45	***	63.54	97.09	41.75	246.96
LCV	Petrol	3.24	0.63	0.11	***	1.79	1.19	0.38	7.33
LCV	Diesel	2.97	2.05	0.11	***	1.95	1.28	0.38	8.73
LCV	Electric	0	0	0.11	***	3.03	5.19	0.38	8.70
HGV <7.5t	Diesel	5.66	3.80	0.80	***	2.60	3.02	0.43	16.31
HGV 7.5-14t	Diesel	8.99	5.29	0.80	***	3.86	3.59	0.79	23.32
HGV 14-28t	Diesel	14.28	8.26	0.80	***	5.28	4.70	0.85	34.17
HGV: Trailer 28-40t	Diesel	19.56	8.53	0.80	***	7.44	5.38	1.07	42.79
Freight train	Weigh-ted Av.	18.16	29.48	3.39	***	297.42	216.00	130.49	694.94

Weighted Av.= Weighted Average Electric/Diesel.
Source: Emission factors for direct emissions are from HBEFA v3.3 and Tremod; emission factors for indirect emissions are from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS as part of the research project.

Table 27: b) Environmental costs per vehicle kilometre (urban) for different vehicle types in Germany at a value factor of 680€/t $CO_{2\ eq}$ in €-cent$_{2020}$ / vehicle kilometre

Vehicle category	Emiss-ion con-cept	Operation: Green-house gases	Operation: Air pollu-tants Exhaust	Operation: Air pollu-tants Abras ion	Operation: Noise	Pre-processes: Infra-structure and vehicles	Pre-processes: Energy supply	Land consu-mption and fragme-ntation	Total
Car	Petrol	11.15	0.28	0.11	***	5.14	2.68	0.36	19.71
Car	Diesel	10.27	1.69	0.11	***	5.77	2.80	0.36	20.99
Car	Electric	0	0	0.11	***	7.35	8.85	0.36	16.66
Small motorcycle	Petrol	4.92	0.69	0.03	***	4.68	1.46	0.12	11.89
Motorcycle	Petrol	6.94	0.38	0.03	***	6.35	2.46	0.16	16.31
Public bus	Diesel	79.79	14.63	0.86	***	12.84	17.20	0.85	126.17
Coach	Diesel	66.09	17.75	0.86	***	15.87	12.92	0.85	114.36
Passenger train, long-distance	Electric	0	0	2.86	***	496.56	722.51	62.63	1,284.56
Passenger train, local transport	Weigh-ted Av.	66.52	23.94	1.46	***	145.73	290.95	41.76	570.35
LCV	Petrol	11.21	0.63	0.10	***	4.10	3.14	0.38	19.56
LCV	Diesel	10.27	2.05	0.10	***	4.42	3.43	0.38	20.66
LCV	Electric	0	0	0.10	***	6.52	12.99	0.38	19.99
HGV <7.5t	Diesel	19.62	3.80	0.80	***	5.90	6.44	0.43	37.00
HGV 7.5-14t	Diesel	31.14	5.29	0.80	***	8.82	8.27	0.78	55.11
HGV 14-28t	Diesel	49.47	8.26	0.80	***	11.97	11.07	0.86	82.43
HGV: Trailer 28-40t	Diesel	67.80	8.53	0.80	***	16.89	13.45	1.07	108.55
Freight train	Weigh-ted Av.	62.96	29.49	3.39	***	686.87	650.68	130.49	1,563.86

Weighted Av.= Weighted Average Electric/Diesel.
Source: Emission factors for direct emissions are from HBEFA v3.3 and Tremod; emission factors for indirect emissions are from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS as part of the research project.

Detailed data on the environmental costs per vehicle kilometre for the different Euronorm classes can be found in the appendix.

To enable a conversion of value factors per vehicle kilometre for the different vehicle types into value factors per passenger kilometre (pkm) and tonne kilometre (tkm), information on the rate of occupation/utilisation by vehicle type is needed. For this purpose, data from the 2018 market investigation of the Federal Network Agency on utilisation rates were used for trains and recommendations from TREMOD 5.8 were used for all other vehicles. This information is summarised in Table 21 below.

Table 2829: Rate of occupation/utilisation by vehicle type

Vehicle type	Passengers / vehicle	Tonnes / vehicle
Car	1.49	
Small motorcycle	1.02	
Motorcycle	1.11	
Public bus	16.5	
Coach	30.4	
Passenger train, long-distance	276	
Passenger train, local transport	81	
Passenger air transport (short- and medium-haul)	105	
Passenger air transport (long-haul)	257	
HGV <7.5t		0.94
HGV 7.5-14t		1.59
HGV 14-28t		3.44
HGV: Trailer 28-40t		10.75
Freight train		499
Freight-air transport		42.1
Inland waterways transport motor vessels		1,060
Inland waterways transport water craft assemblies		1,945

The value factors for air transport, proportionally account for belly freight.
No utilisation data is available for light commercial vehicles (LNF).
Source: TREMOD 5.8 or Bundesnetzagentur, Marktuntersuchung Eisenbahn 2018.

With these factors, all costs expressed in vehicle kilometres can be converted into passenger kilometres (pkm) or tonne kilometres (tkm).

Table 22 exemplarily illustrates the resulting average environmental costs (across all routes, emission factors for 2016) per passenger or tonne kilometre. As noise costs are not calculated based on mileage, they are not included here. The environmental costs when adopting a value factor of 680 EUR/t of greenhouse gases is illustrated separately in Table 22.

Table 3031: Environmental costs per passenger or tonne kilometre for various vehicle types in Germany in €-cent$_{2020}$ / pkm or tkm

Vehicle type		Unit	Total environmental costs (GHG value factor 195 EUR/t $_{CO2}$ eq.)	Total environmental costs (GHG value factor 680 EUR/t $_{CO2}$ eq.)
Car	Petrol	€-cent/Pkm	4.66	12.72
Car	Diesel	€-cent/Pkm	5.43	13.05
Car	Electric	€-cent/Pkm	4.41	11.12
Small motorcycle	Petrol	€-cent/Pkm	5.21	12.23
Motorcycle	Petrol	€-cent/Pkm	5.55	14.73
Public bus	Diesel	€-cent/Pkm	2.70	6.90
Coach	Diesel	€-cent/Pkm	1.16	2.85
Passenger train, long-distance	Electric	€-cent/Pkm	1.88	4.65
Passenger train, local transport	Weighted av.	€-cent/Pkm	3.01	7.00
Passenger air transport	Short & Medium-distance	€-cent/Pkm	9.00	23.7
Passenger air transport	Long distance	€-cent/Pkm	6.18	16.06
HGV <7.5t	Diesel	€-cent/tkm	15.61	38.93
HGV 7.5-14t	Diesel	€-cent/tkm	12.29	31.54
HGV 14-28t	Diesel	€-cent/tkm	7.52	19.58
HGV: Trailer 28-40t	Diesel	€-cent/tkm	2.97	7.96
Freight train	Weighted av.	€-cent/tkm	1.38	3.12
Freight-air traffic		€-cent/tkm	49.13	126.51
Motor vessels (inland waterways transport)		€-cent/tkm	2.14	3.66
Water craft assemblies (inland waterways transport)		€-cent/tkm	2.15	3.67

Weighted. av. = Weighted average electric/diesel.
The value factors for air transport proportionally account for belly freight. Source: Calculations by INFRAS as part of the research project.

5 Value factors for nitrogen (N) and phosphorus (P) emissions

Environmental damages from nitrogen and phosphorus emissions accrue along various impact pathways. Nitrogen emissions, among other things, pollute the groundwater and air and thereby entail health costs as well as water treatment costs; whereas nitrogen and phosphorus emissions, among other things, put a strain on surface waters through eutrophication and acidification and thus lead to the impairment and loss of ecosystems. The costs that stem from emissions into the air, groundwater as well as surface waters are presented individually below. For each specific application, the relevant impact pathway or impacts pathways must be determined. No damage costs could be identified for the acidification of soils and the resulting ecosystem damages.

5.1 Emissions into the air (direct and indirect)

No data regarding the harmful effects of emission of phosphorus into the air are available and consequently not damage costs can be specified. If no data on the emission source are available, we recommend using the following value factors pursuant to the respective harmful effect for the emission of nitrogen (values in conformity with the value factors for N-compounds in the chapter on air pollutants and the value for N_2O in the chapter on greenhouse gases):

Table 32: Environmental costs of nitrogen (N) emissions to air (direct and indirect, unknown source)

N-compund	Impact category	Value factor €2020 /kg N
Nitrogen oxides (NO_x)	- health	49.9
	- biodiversity	9.1
	- crop failures	2.8
	- building/Material	0.5
	Total	**62.2**
Ammonia (NH_3)	- health	27.7
	- biodiversity	13.4
	- crop failures [20]	-0.1
	- building/Material	0
	Total	**40.9**
Nitrous oxide (laughing gas - N_2O)	- climate impact	78.9
	- ozone depletion [21]	1.2
	Total	**80.2**

Source: Schäppi et al. (2019), own calculations; costs for biodiversity losses include damages as a result of eutrophication and acidification through deposition. Note: In contrast to the chapters "Air pollutants" and "Greenhouse gases", the value factors here refer to 1kg N, not to 1kg of the respective chemical compound (NOx, NH3, N2O); 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.

5.2 Emissions into surface water and groundwater

When determining the damage caused by the emission or discharge 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 arises. 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 the fact that in general both substances exhibit concentration levels in the water bodies which are too high, implying that

[20] Crop failures due to soil acidification are not considered here due to lack of data.
[21] According to Compton et al. (2011) based on Ravishankara et al. (2009).

both substances have a potential for causing damages. The value factors specified below should therefore be interpreted as a **lower bound for damages,** since applying a value factor of 0 for the non-limiting substance ignores that in most cases the concentration of this substance is already above the level that would be appropriate for a good status of the water body.

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 environmental costs of N and P are specified for the case 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 assessing the environmental costs on a case-by-case basis, it must be determined which substance has a limiting effect. To avoid double counting when ascertaining the total costs, all of the environmental costs are to be attributed to this substance.

Table 33: Environmental costs of nitrogen emissions to groundwater and of nitrogen and phosphorus as respective growth-limiting factors in surface waters

Substance	Impact pathway	Value factor €$_{2020}$ / kg N
Nitrogen	**Groundwater**	1.9
	Inland waters	7.3
	Coastal and marine waters	20.8
Phosphorus	**Inland waters**	153.5
	Coastal and marine waters	441.4

Source: Schäppi et al (2019), own calculations.

If nitrogen and phosphorous are emitted into surface water, the damaging effects first materialise in the inland water body 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 phosphorous 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:

Table 34: Environmental costs of nitrogen and phosphorus emissions into surface waters when it is unknown which is the limiting substance in the affected water bodies

	Value factor nitrogen €$_{2020}$ / kg N	Value factor phosphorus €$_{2020}$ / kg P
Emission into surface water	20.8	153.5

Source: Schäppi et al. (2019), own calculations.

These average value factors for emissions to 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 the fact that in most inland waters plant growth is limited by phosphorus, whereas in marine and coastal waters nitrogen is limiting in most cases. Therefore, for the total damage caused by discharge into surface waters (inland waters + sea), the value factor of 20.8 €/kg (value factor for discharge into marine waters) should be used for nitrogen, and the value factor of 153.5 €/kg (value factor for discharge into inland waters) for phosphorus. This way dobule counting is avoided.

5.3 Value factors for nitrogen and phosphorus from agriculture

The agricultural sector is among the most relevant emitters of nitrogen and phosphorus due to the application of manure and mineral fertilisers. Besides the intended uptake by plants, nitrogen and phosphorus also enter the environment via various pathways, thereby causing environmental damages.

Average value factors for nitrogen application in agricultural practice:

6.30 € per kg nitrogen.

This value is the result of calculating a weighted average (cf. UBA (2020) [22]) of the effects of NO_X, N_2O and NH_3 emissions from the application of mineral and organic fertilisers as well as from the management of organic soils, nitrate leaching with seepage water from agricultural land and N input from agricultural land into surface waters via runoff, erosion and drainage.

Average value factors for phosphorus application in agricultural practice:

4.44 € per kg phosphorus.

This value is an average of the effects of P emissions from the application of mineral and organic fertilisers. The total amounts of phosphorus [23] applied were put in relation to the amounts of phosphorus entering the water bodies through input pathways, which are mainly attributable to agricultural activity (erosion, groundwater, surface runoff, drainage) [24].

[22] UBA: Reactive nitrogen fluxes in Germany 2010-2014 (DESTINO Report 2), May 2020, Fig. 12-1 p. 140

[23] Farm manure: DESTATIS (2017b); mineral fertiliser: DESTATIS (2019); conversion factor P_2O_5 to P (= 0.436): State Institute for Agriculture and Horticulture, Saxony-Anhalt (2018).

[24] Results from Modeling of Regionalized Emissions (MoRe). Values for 2015.

6 Value factors for building materials

The production of building materials generates a wide range of environmental costs: the extraction of raw materials destroys ecosystems, emits greenhouse gases and air pollutants, and releases toxic substances into soils and water bodies. Further emissions of various kinds accrue during transport and processing.

When assessing the environmental costs of building materials, it is important to distinguish between the use of primary building materials and the use of recycled building materials. By using recycled building materials, the environmental costs of raw material extraction can be avoided. The costs of processing can also be reduced if the processing of the recycled building materials is less energy intensive than the processing of the primary building materials.

As in the entire document, the 2016 emission factors serve as the basis for determining the value factors for building materials. This implies that processes that were introduced after 2016 or increases in the use of renewable energies after 2016 have not been taken into account.

The environmental costs of building materials depend on the environmental effects induced by the latter along the supply chain. Where available, data on such effects are collected in life cycle assessment (LCA) databases. The data used in the Methodological Convention are largely sourced from the EcoInvent[25] database. The costs reported below do not consider the use phase of the building materials (e.g. the environmental costs of building use) nor their deconstruction, recycling or disposal. Hence, they do not cover the entire life cycle. Consequently, no conclusive recommendations for specific construction methods can be derived from these data alone.

Furthermore, it must be borne in mind that the LCA data do not consider all environmental effects. Especially in the initial part of the supply chain (raw material extraction), the data are often incomplete (concerning the consequences for biodiversity, accidents, etc.). On top of that the valuation of ecosystem damage used as a basis here (according to Ott et al. 2007) must be considered to be very conservative. The specified **value factors therefore represent lower limits that significantly underestimate the actual costs incurred, depending on the building material.**

Looking at the recommendations on the environmental costs of building materials, two further factors, which are at least as important for the comparison of buildings, must be kept in mind: Firstly, besides the building materials used, the construction method (e.g. insulated or not) is essential with regard to, e.g., the resulting expenditure for heat and insulation. Likewise, an aluminium construction, for example, is significantly lighter than a steel construction of similar function, which must be taken into account when interpreting the value factors per tonne of building material.

Secondly, the actual amount of materials used depends on the specific function of the building. Consequently, building materials can only be compared if they are used in buildings of similar function. Likewise, the use of the buildings must also be considered with regard to these aspects, as this also has a substantial impact on the environmental costs incurred in the course of the buildings' life cycle.

[25] For the itemised data, see the status paper (on request).

Taking these indications into account, the following can be stated regarding the environmental costs (according to the cradle-to-gate concept [26]) of building materials:

- Non-ferrous metals have relatively high environmental costs per tonne despite the incomplete consideration of raw material extraction.
- Steel and plastics (insulation and PVC pipes) are carbon intensive materials and also have environmental costs which are quite high.
- Sand and crushed stone have the lowest environmental costs per tonne as they are quite easily extracted and require little or no further processing (only optional crushing and washing). Bricks have slightly higher environmental costs compared to sand and crushed stone due to the production steps for brick production.
- Concrete and asphalt have a relatively low environmental cost per tonne, however, as they are used in very large quantities in construction projects, they have a very large overall environmental impact.

The high environmental costs for most of the timber options stem to a large extent from land use (these account for between about 40% and 75%). Despite the high costs, the very conservative consideration of biodiversity damage from timber production means that the true costs are likely to be significantly underestimated. This is especially true for many types of timber from tropical areas.

Table 35: Environmental costs of building materials (+) and environmental benefits from recycling building materials (-)

Category	Variant	Unit	Characteristics	Value factor in €/unit
Steel	Surface-finished, cold-rolled sheet metal, cradle-to-gate	1,000 kg		580
Steel	Hot-dip galvanised sheet metal, cradle-to-gate	1,000 kg		640
Steel	Reinforcing steel, cradle-to-gate	1,000 kg		550
Steel	Steel profile, cradle-to-gate	1,000 kg		580
Steel	Welded pipe, cradle-to-gate	1,000 kg		620
Steel, recycling potential	all above categories	1,000 kg		-350
Non-ferrous metals	Aluminium sheet metal, 60% recycled content	1,000 kg	60% scrap	**2480**
Non-ferrous metals, recycling potential	Aluminium sheet metal, 60% recycled content	1,000 kg	60% scrap	**-970**
Non-ferrous metals	Copper pipe, 71% recycled content	1,000 kg	71% scrap	**7150**
Non-ferrous metals, recycling potential	Copper pipe, 71% recycled content	1,000 kg	71% scrap	-2180
Timber	Sawn softwood EU	$1 m^3$	540 kg/m^3 (at 20% humidity)	320
		1,000 kg		590

[26] The cradle-to-gate concept covers all upstream chains and production processes of the building material. The environmental impacts that accure during transport, use and disposal of the finished building material are therefore not included.

Timber	Sawn hardwood EU	1m³ 1,000 kg	780 kg/m³ (at 20% humidity)	180 230
Timber	Sawn tropical hardwood, Cameroon (CM)	1m³ 1,000 kg	1,200 kg/m³ (at 20% humidity)	1440 1200
Timber	Sawn tropical softwood, Brazil (BR)	1m³ 1,000 kg	600 kg/m³ (at 20% humidity)	1000 1670
Timber	Roundwood, hardwood Eucalyptus, Thailand (TH)	1m³ 1,000 kg	990 kg/m³ (at 20% humidity)	80 80
Timber	Plywood panel (interior use)	1,000 kg	780 kg/m³ (at 20% humidity)	540
Timber	Oriented Strand Board (OSB board)	1,000 kg	540 kg/m³ (at 20% humidity)	400
Concrete	Concrete C20/25	1,000 kg		19
Concrete	Concrete C30/37	1,000 kg		23
Concrete	Concrete C35/45	1,000 kg		26
Concrete	Concrete C45/55	1,000 kg		30
Concrete	Concrete C50/60	1,000 kg		32
Asphalt	Asphalt pavement, 0% reclaimed asphalt pavement (RAP)	1m²; 1.8 kg/m²		17
Asphalt	Asphalt pavement, 7% reclaimed asphalt pavement (RAP)	1m²; 1.8 kg/m²		16
Asphalt	Asphalt pavement, 24% reclaimed asphalt pavement (RAP)	1m²; 1.8 kg/m2		15
Stony building materials	Crushed stone	1,000 kg		2
Stony building materials	Sand	1,000 kg		2
Stony building materials	Clay bricks	1,000 kg		72
Stony building materials	Sandlime bricks	1,000 kg		45
Plastics/insulation	PVC pipes	1,000 kg		580
Plastics/insulation	Polystyrene foam (EPS) insulation	1,000 kg	Density 20 kg/m³	720
Plastics/insulation	Glass wool insulation	1,000 kg	Density 10-100 kg/m³	620
Plastics/insulation	Mineral wool insulation	1,000 kg	Density 46 kg/m³	450
Plastics/insulation	Polyurethane rigid foam insulation	1,000 kg	Density 33 kg/m³	1310

Note: The environmental costs of the different steel variants factor in the average proportions of steel scrap used in Germany in the production of the respective variants. The overall recycling rate in steel production in Germany is approx. 44% (see statistical yearbook of the steel industry). Recycling potential represents the environmental benefit from additional recycled material brought to the market by recycling the building material. The corresponding value factors therefore have a negative sign. If a building material already contains a recycled content, the recycling potential is only calculated for the remaining share of primary building material.

Source: Bijleveld M. et al (2019).

7 Climate costs in agriculture

Agricultural production is responsible for a considerable share of greenhouse gas emissions in Germany.

In regard to "crop production", value factors for the cultivation of important agricultural crops are recommended below. The crops which are produced in the largest quantities in Germany are wheat, barley, potatoes and silage maize. The latter are either processed for food or animal feed. Additionally, soya is used as animal feed. Besides these crops, we also consider oilseed in this assessment of climate costs in agricultural production, namely domestic rapeseed oil as well as palm oil imports (from Malaysia).

With respect to "animal production", the production of milk [27] as well as beef, pork and poultry meat are considered. All animal products are valued in kilograms live weight at farmgate. Further refining steps as well as packaging are not included in the value factors. The value factors therefore refer to the agricultural output at farmgate, not to the final goods (i.e. 1 litre of milk at farmgate and not 1 litre of milk after processing or in the supermarket).

Plant products (incl. oilseeds):

- Wheat
- Barley
- Potatoes
- Maize (grain and silage maize)
- Soy (Europe and South America)
- Rapeseed oil
- Palm oil (import)

Animal products:

- Milk
- Beef
- Pork
- Poultry

The calculations are based on a climate value factor of 195 €$_{2020}$ / t $CO_{2\ eq}$. or a climate value factor of 680 €$_{2020}$ / t $CO_{2\text{-}eq}$., both for the year 2020. The best available data sets refer to cultivation in Switzerland (wheat, barley, potatoes, pork, poultry, all of the above from organic farming ; grain maize, silage maize, soy, all of the latter from integrated and organic farming, rapeseed oil average, beef suckler cow husbandry, all of the latter from integrated farming), Germany (wheat, barley, milk, beef large-scale fattening, pork, all of the above from conventional farming), Canada (potatoes without indication of production type), Brazil (South American soy), Malaysia (palm oil), France (poultry conventional farming).

[27] A separate REFOPLAN project has been carried out on the environmental costs of milk production: "Visibility of hidden environmental costs of agriculture using the example of milk production systems" (FKZ: 3717 11 238 0).

For both pork and poultry, the Ecoinvent database does not contain any values for Germany or close foreign countries. The data are sourced from the Agroscope Research Station (ART 2012).

The following table specifies the climate costs of plant-based food production. A distinction is made between conventional, integrated production (IP) [28]and organic production.

Table 36: Climate related value factors for the production of plant-based food (climate value factors €195 and €680)

Products	Production type	195 € / t $_{CO2\ eq}$ € cent / kg	680 € / t $_{CO2\ eq}$ € cent / kg
Wheat	Conventional	10.92	38.08
	Organic	7.96	27.77
Barley	Conventional	9.95	34.68
	Organic	7.17	25.01
Potatoes	no information	4.10	14.28
	Organic	2.47	8.61
Maize (grains)	integrated production	7.15	24.93
	Organic	10.56	36.83
Silage maize	integrated production	0.96	3.36
	Organic	0.92	3.21
Soy (Europe)	integrated production	14.53	50.66
	Organic	11.88	41.44
Soy (South America)	Conventional	90.29	314.84

Source: Own calculation based on Ecoinvent Version 3.5 and UBA 2019, data origin depending on availability Germany, Switzerland, Canada and Brazil.

The plant-based animal feed and food grown in Germany cause climate costs of between around 0.92 and 14.53 €-cents (or 3.21 and 50.66 €-cents) per kilogram, with generally lower climate costs in organic farming than in conventional farming. The lowest climate costs for food are caused by potato production (around 2.47 to 4.10 €-cents per kg) and for feed by silage maize (around 0.92 to 0.96 €-cents per kg). The production of barley, wheat and (grain) maize causes climate costs that lie in the middle (around 7.15 to 10.92 €-cents per kg, each calculated with a climate related value factor of 195€ /t CO2-eq.).

By far the highest climate costs are caused by imported soy from South America (Brazil). The value factor accounts for land conversion, but not the transport to Europe. As a significant part of the feed in agriculture is imported as soy, this data set was also considered for comparison purposes. Due to the climate impact of land conversion, the climate costs of imported soy are

[28] Integrated production (IP) is an intermediate step between conventional agriculture and organic agriculture. Integrated production uses methods that have the least possible negative impact on the environment, but without adopting all the restrictions of organic farming. In Switzerland, IP regulations are clearly defined. In Germany there is no clear functional equivalent.

about six times higher (over 80 € cents per kg) than those of soy produced in Europe. The difference is even higher when using organic farming methods in Europe.

Table 37: Climate related value factors of oilseed production (climate value factors of €195 and €680)

Products	Production type	195 € / t $CO_{2\,eq}$ € cent / kg	680 € / t $CO_{2\,eq}$ € cent / kg
Rapeseed oil	Average	32.66	113.90
Palm oil (import)	Incl. use of land	73.34	255.75

Source: Own calculation based on Ecoinvent Version 3.5 and UBA 2019.

The climate costs of oilseeds amount to 32.66 €-cents (or 113.90 €-cents) for rapeseed oil and 73.34 €-cents (or 255.75 €-cents) per kg for palm oil. In the case of palm oil produced in Malaysia, the climate impact of land use is very significant due to the clearing of primary forests to grow oil palms. In Germany, on the other hand, land conversion from primary forests or other CO_2 sinks is rare.

The following table shows the climate related value factors for animal food production.

Table 38: Climate related value factors for animal food production (climate value factors €195 and €680)

Products	Production type	195 € / t $CO_{2\,eq}$ € cent / kg	680 € / t $CO_{2\,eq}$ € cent / kg
Milk (ECM)	Conventional	26	90
	Bandwidth in literature	16 - 57	55 - 198
Beef (live weight)	Cattle fattening, conventional	153	533
	Suckler cow husbandry, integrated production	275	959
Pork (live weight)	Conventional	64	224
	Organic	66	231
Poultry (live weight)	Conventional	45	156
	Organic	41	143

ECM = energy-corrected milk quantity: milk converted to the same energy content in order to be able to compare milk with different fat and protein contents. Large-scale fattening refers to the fattening of calves from dairy farming; suckler cow farming refers to the rearing of cattle solely for meat production.

Source: Own calculation based on Ecoinvent version 3.5, Bystricky et al., 2015, ART 2012 and UBA 2019.

For the production of milk[29], climate related value factors can be calculated based on emission factors that can be found in the literature, ranging from 16 to 57 €-cents (or 55-198 €-cents) per kg of milk (ECM) [30] on average. We recommend using an average value based on Bystricky et al. (2015) and UBA (2019b). This average is found at around 26 €-cent (or 90 €-cent) per kg milk (ECM) at farmgate.

Assessing the climate costs for meat production yields an average climate cost of € 1.53 (or € 5.33) per kg beef live weight for conventional large-scale cattle fattening (calves from dairy farming) in Germany and € 2.75 (or € 9.59) per kg beef live weight for suckler cow farming (pure meat production) (integrated production in Switzerland). The data show that the climate costs of large-scale cattle fattening are lower than those of suckler cow husbandry, mainly because in the case of large-scale cattle fattening, part of the emissions from suckler cows can be attributed to milk production.

The climate related value factors for a kilogram of pork (live weight) range between 64 €-cents (or 2.24 €) per kg for conventional production and 66 €-cents (or 2.31 €) per kg for organic production, depending on the region. The production of poultry meat (live weight) results in climate costs of between 38 and 41 €-cents per kg.

For an application of the presented value factors from a consumer perspective, other system boundaries would have to be chosen, as the share of slaughtered meat in the live weight differs depending on the type of animal. In addition, when comparing foods from a consumer perspective, emissions from further processing and transport must also be taken into account.

All environmental value factors presented here are expressed in €-cents or € per kg. When comparing foods from a nutritional perspective, on the other hand, the energy content should be taken into account. This means that the climate related value factors should be offset against the kilojoule values per kilogram in order to compare the climate impact of pork with that of potatoes, for example.

[29] A much more differentiated presentation of the environmental costs of milk production has been carried out in the REFOPLAN project "Sichtbarmachung versteckter Umweltkosten der Landwirtschaft am Beispiel von Milchproduktionssystemen" (FKZ: 3717 11 238 0).
[30] Energy corrected milk quantity (ECM).

8 Appendix

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 as well as the damage to nature and landscape caused by road construction are summarised in the life cycle category.

Table 3940: a) Value factors transport: differentiated by emission category (Euronorm) for the different vehicle types at a value factor of 195€/t $CO_{2\ eq,}$ in €-cent$_{2020}$ / vehicle kilometre

		Operation			Pre-processes		Land consumption and fragmentation	Total
Vehicle category	EURO standard	Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and vehicles	Energy supply		
Car, Diesel	Euro 0	3.07	1.83	0.03	2.53	1.23	0.36	9.05
	Euro 1	3.35	1.95	0.03	2.53	1.35	0.36	9.57
	Euro 2	3.16	1.90	0.03	2.53	1.27	0.36	9.25
	Euro 3	2.91	1.78	0.03	2.53	1.17	0.36	8.78
	Euro 4	2.77	1.39	0.03	2.53	1.12	0.36	8.19
	Euro 5	2.52	1.82	0.03	2.53	1.02	0.36	8.27
	Euro 6	2.36	1.03	0.03	2.53	0.95	0.36	7.27
Car, petrol	Euro 0	4.30	2.44	0.03	2.22	1.62	0.36	10.97
	Euro 1	3.91	1.98	0.03	2.22	1.47	0.36	9.96
	Euro 2	3.77	1.27	0.03	2.22	1.43	0.36	9.07
	Euro 3	3.48	0.29	0.03	2.22	1.33	0.36	7.71
	Euro 4	3.13	0.28	0.03	2.22	1.19	0.36	7.21
	Euro 5	2.79	0.20	0.03	2.22	1.06	0.36	6.66
	Euro 6	2.63	0.20	0.03	2.22	1.00	0.36	6.44
Small motorbike (petrol)	Euro 0	2.26	1.62	0.01	2.22	0.92	0.12	7.14
	Euro 1	2.34	0.80	0.01	2.22	0.95	0.12	6.45
	Euro 2	1.85	0.47	0.01	2.22	0.75	0.12	5.43
	Euro 3	1.51	0.35	0.01	2.22	0.61	0.12	4.82

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

Vehicle category	EURO standard	Operation			Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and vehicles	Energy supply		
	Euro 1	2.00	0.73	0.01	2.39	1.10	0.16	6.38
	Euro 2	1.85	0.62	0.01	2.39	1.01	0.16	6.04
	Euro 3	1.92	0.37	0.01	2.39	1.05	0.16	5.89
								12.87
	Euro 1	3.99	2.96	0.03	1.79	1.53	0.38	10.67
								8.53
	Euro 3	3.56	0.33	0.03	1.79	1.36	0.38	7.45
								6.72
	Euro 5	2.75	0.19	0.03	1.79	1.06	0.38	6.19
								5.77
Light commercial vehicle (diesel)	Euro 0	5.53	5.11	0.03	1.95	1.99	0.38	14.98
								13.46
	Euro 2	4.54	3.47	0.03	1.95	1.63	0.38	12.01
								10.21
	Euro 4	3.55	2.07	0.03	1.95	1.27	0.38	9.26
	Euro 5	3.30	1.77	0.03	1.95	1.18	0.38	8.61
	Euro 6	3.05	0.61	0.03	1.95	1.10	0.38	7.13
Public bus	Euro 0	20.59	36.41	0.16	5.18	6.37	0.85	69.57
	Euro 1	17.86	22.37	0.16	5.18	5.52	0.85	51.94
								52.28
	Euro 3	19.85	19.55	0.16	5.18	6.14	0.85	51.73
								46.35
	Euro 5	21.30	9.59	0.16	5.18	6.59	0.85	43.68
								34.41
Coach	Euro 0	14.45	23.12	0.09	6.50	5.01	0.85	50.03
								42.79
	Euro 2	12.74	16.94	0.09	6.50	4.42	0.85	41.55

		Operation			Pre-processes		Land consumption and fragmentation	Total
Vehicle category	EURO standard	Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and vehicles	Energy supply		
	Euro 4	13.58	8.50	0.09	6.50	4.71	0.85	34.23
	Euro 5	14.17	6.25	0.09	6.50	4.91	0.85	32.78
	Euro 6	14.33	0.80	0.09	6.50	4.97	0.85	27.55
								26.13
	Euro I	6.11	7.47	0.07	3.86	2.97	0.79	21.27
								20.94
	Euro III	6.23	5.28	0.07	3.86	3.03	0.79	19.26
								17.7
	Euro IV SCR	6.12	2.73	0.07	3.86	2.98	0.79	16.55
								16.88
	Euro V SCR	6.12	1.64	0.07	3.86	2.98	0.79	15.47
								14.19
Heavy goods vehicle (>7.5t-12t)	80ties	9.47	17.48	0.07	3.86	4.00	0.79	35.68
								27.13
	Euro II	8.17	10.46	0.07	3.86	3.45	0.79	26.80
								24.48
	Euro IV EGR	8.65	5.02	0.07	3.86	3.65	0.79	22.05
								20.58
	Euro V EGR	8.76	3.77	0.07	3.86	3.70	0.79	20.95
								19.22
	Euro VI	8.51	0.41	0.07	3.86	3.59	0.79	17.23
Heavy goods vehicle (>12t-14t)	80ties	10.00	18.48	0.07	3.86	4.22	0.79	37.43

		Operation			Pre-processes		Land consumptio n and fragmentati on	Total
Vehicle category	EURO standar d	Greenh ouse gases	Air polluta nts Exhaus t	Air polluta nts Abrasio n	Infrastr ucture and vehicles	Energy supply		
	Euro I	8.86	11.15	0.07	3.86	3.74	0.79	28.48
	Euro II	8.62	11.18	0.07	3.86	3.64	0.79	28.16
	Euro III	9.01	8.19	0.07	3.86	3.80	0.79	25.73
								22.99
	Euro IV SCR	8.71	4.11	0.07	3.86	3.68	0.79	21.23
								21.85
	Euro V SCR	8.77	2.75	0.07	3.86	3.70	0.79	19.95
								17.88
Heavy goods vehicle (>14t-20t)	80ties	12.12	22.11	0.07	5.28	4.93	0.85	45.37
								33.95
	Euro II	9.98	13.47	0.07	5.28	4.06	0.85	33.72
								30.83
	Euro IV EGR	10.33	6.61	0.07	5.28	4.20	0.85	27.36
	Euro IV SCR	9.93	5.28	0.07	5.28	4.04	0.85	25.45
	Euro V EGR	10.51	5.06	0.07	5.28	4.28	0.85	26.06
	Euro V SCR	9.98	3.69	0.07	5.28	4.06	0.85	23.94
	Euro VI	10.23	0.63	0.07	5.28	4.16	0.85	21.23
								49.18
	Euro I	12.35	16.17	0.07	5.28	5.03	0.85	39.76
								39.64
	Euro III	12.54	12.30	0.07	5.28	5.10	0.85	36.15
	Euro IV EGR	12.33	8.29	0.07	5.28	5.02	0.85	31.84

		Operation			Pre-processes		Land consumption and fragmentation	Total
Vehicle category	EURO standard	Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and vehicles	Energy supply		
	Euro IV SCR	11.91	6.00	0.07	5.28	4.85	0.85	28.97
								30.12
	Euro V SCR	12.01	4.10	0.07	5.28	4.89	0.85	27.2
								24.06
Heavy goods vehicle (>26t-28t)	Euro I	12.89	16.9	0.07	5.28	5.24	0.85	41.24
								41.07
	Euro III	13.28	12.65	0.07	5.28	5.41	0.85	37.54
								33.16
	Euro IV SCR	12.67	6.21	0.07	5.28	5.15	0.85	30.24
								31.31
	Euro V SCR	12.7	4.22	0.07	5.28	5.17	0.85	28.30
	Euro VI	12.93	0.68	0.07	5.28	5.26	0.85	25.09
Heavy goods vehicle (>28t-32t)	Euro I	15.01	19.51	0.07	5.28	5.51	0.85	46.24
	Euro II	14.87	19.31	0.07	5.28	5.46	0.85	45.85
	Euro III	15.33	14.37	0.07	5.28	5.63	0.85	41.53
	Euro IV EGR	15.31	9.62	0.07	5.28	5.62	0.85	36.76
	Euro IV SCR	14.81	6.99	0.07	5.28	5.44	0.85	33.45
	Euro V EGR	15.60	7.16	0.07	5.28	5.73	0.85	34.70
	Euro V SCR	14.90	4.64	0.07	5.28	5.47	0.85	31.22
	Euro VI	15.18	0.75	0.07	5.28	5.57	0.85	27.71

		Operation			Pre-processes		Land consumption and fragmentation	Total
Vehicle category	EURO standard	Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and vehicles	Energy supply		
	Euro II	14.56	19.56	0.07	5.28	5.35	0.85	45.68
	Euro III	15.00	14.75	0.07	5.28	5.51	0.85	41.46
								36.43
	Euro IV SCR	14.43	6.80	0.07	5.28	5.30	0.85	32.73
								34.33
	Euro V SCR	14.54	4.56	0.07	5.28	5.34	0.85	30.64
								27.10
Road trains/semitrailers (>20-28t)	80ties	14.04	22.71	0.07	5.28	5.15	0.85	48.11
								39.33
	Euro II	12.13	15.88	0.07	5.28	4.45	0.85	38.67
								35.26
	Euro IV EGR	12.54	7.98	0.07	5.28	4.60	0.85	31.33
	Euro IV SCR	12.1	6.02	0.07	5.28	4.44	0.85	28.77
	Euro V EGR	12.74	5.98	0.07	5.28	4.68	0.85	29.61
	Euro V SCR	12.16	4.01	0.07	5.28	4.46	0.85	26.85
	Euro VI	12.39	0.62	0.07	5.28	4.55	0.85	23.77
								50.22
	Euro I	13.12	16.87	0.07	5.28	4.81	0.85	41.01
								40.32
	Euro III	13.26	12.44	0.07	5.28	4.87	0.85	36.77
								32.57

Vehicle category	EURO standard	Operation			Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and vehicles	Energy supply		
	Euro V EGR	13.48	6.15	0.07	5.28	4.95	0.85	30.78
	Euro V SCR	12.93	4.02	0.07	5.28	4.75	0.85	27.91
	Euro VI	13.12	0.60	0.07	5.28	4.82	0.85	24.74
Road trains/semitrailers (>34-40t)	80ties	16.73	27.11	0.07	7.44	6.14	1.07	58.58
	Euro I	14.67	19.14	0.07	7.44	5.39	1.07	47.79
	Euro II	14.48	19.16	0.07	7.44	5.32	1.07	47.56
	Euro III	14.88	14.53	0.07	7.44	5.46	1.07	43.46
	Euro IV EGR	14.78	9.66	0.07	7.44	5.43	1.07	38.45
	Euro IV SCR	14.34	7.01	0.07	7.44	5.27	1.07	35.21
	Euro V EGR	15.12	7.23	0.07	7.44	5.55	1.07	36.5
	Euro V SCR	14.48	4.66	0.07	7.44	5.32	1.07	33.06
	Euro VI	14.68	0.67	0.07	7.44	5.39	1.07	29.34

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: Calculations by INFRAS as part of the research project.

Table 4142: b) Value factors transport: differentiated by emission category (Euronorm) for the different vehicle types at a value factor of 680€/t $CO_{2\ eq,}$ in €-cent$_{2016}$ / vehicle kilometre

Vehicle category	EURO standard	Operation: Greenhouse gases	Operation: Air pollutants Exhaust	Operation: Air pollutants Abrasion	Pre-processes: Infrastructure and -vehicles	Pre-processes: Energy supply	Land consumption and fragmentation	Total
								21.92
	Euro 1	11.62	1.95	0.03	5.77	3.64	0.36	23.35
								22.42
	Euro 3	10.09	1.78	0.03	5.77	3.16	0.36	21.18
								20.14
	Euro 5	8.74	1.82	0.03	5.77	2.74	0.36	19.45
	Euro 6	8.18	1.03	0.03	5.77	2.56	0.36	17.92
Car, petrol	Euro 0	14.92	2.44	0.03	5.14	4.29	0.36	27.18
	Euro 1	13.55	1.98	0.03	5.14	3.88	0.36	24.94
	Euro 2	13.06	1.27	0.03	5.14	3.77	0.36	23.62
								21.38
	Euro 4	10.85	0.28	0.03	5.14	3.16	0.36	19.8
								18.21
	Euro 6	9.12	0.20	0.03	5.14	2.65	0.36	17.49
								16.33
	Euro 1	8.13	0.80	0.01	4.68	2.18	0.12	15.92
								13.4
	Euro 3	5.23	0.35	0.01	4.68	1.40	0.12	11.79
								17.39
	Euro 1	6.93	0.72	0.01	6.35	2.50	0.16	16.68
								15.87
	Euro 3	6.64	0.36	0.01	6.35	2.40	0.16	15.93
								29.09
	Euro 1	13.8	2.96	0.03	4.10	4.05	0.38	25.31

Vehicle category	EURO standard	Operation			Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and -vehicles	Energy supply		
	Euro 3	12.31	0.33	0.03	4.10	3.61	0.38	20.76
	Euro 4	10.67	0.26	0.03	4.10	3.13	0.38	18.57
	Euro 5	9.52	0.19	0.03	4.10	2.79	0.38	17.00
								15.67
Light commercial vehicle (diesel)	Euro 0	19.16	5.11	0.03	4.42	5.35	0.38	34.45
								31.51
	Euro 2	15.75	3.47	0.03	4.42	4.40	0.38	28.44
								24.15
	Euro 4	12.28	2.07	0.03	4.42	3.43	0.38	22.6
								21.18
	Euro 6	10.59	0.61	0.03	4.42	2.96	0.38	18.98
								138.78
	Euro 1	61.89	22.36	0.16	12.84	14.87	0.85	112.97
	Euro 2	62.43	22.51	0.16	12.84	15.00	0.85	113.79
	Euro 3	68.78	19.56	0.16	12.84	16.53	0.85	118.71
	Euro 4	71.69	13.07	0.16	12.84	17.22	0.85	115.83
	Euro 5	73.85	9.59	0.16	12.84	17.74	0.85	115.02
								104.75
Coach	Euro 0	50.10	23.12	0.09	15.87	13.50	0.85	103.54
								93.07
	Euro 2	44.17	16.94	0.09	15.87	11.91	0.85	89.83
								89.87
	Euro 4	47.06	8.50	0.09	15.87	12.68	0.85	85.06
								85.38
	Euro 6	49.66	0.80	0.09	15.87	13.39	0.85	80.67
								52.40
	Euro I	21.17	7.47	0.07	8.82	6.34	0.78	44.65
	Euro II	20.51	7.41	0.07	8.82	6.14	0.78	43.74

Vehicle category	EURO standard	Operation			Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and - vehicles	Energy supply		
	Euro IV EGR	21.93	3.57	0.07	8.82	6.57	0.78	41.75
	Euro IV SCR	21.21	2.73	0.07	8.82	6.35	0.78	39.97
	Euro V EGR	22.21	2.63	0.07	8.82	6.65	0.78	41.18
	Euro V SCR	21.22	1.65	0.07	8.82	6.35	0.78	38.90
	Euro VI	21.51	0.24	0.07	8.82	6.44	0.78	37.88
Trucks (>7.5t-12t)	80ties	32.83	17.48	0.07	8.82	9.22	0.78	69.21
								57.48
	Euro II	28.29	10.46	0.07	8.82	7.95	0.78	56.37
	Euro III	29.75	7.55	0.07	8.82	8.36	0.78	55.33
	Euro IV EGR	29.96	5.02	0.07	8.82	8.42	0.78	53.08
								50.74
	Euro V EGR	30.34	3.76	0.07	8.82	8.52	0.78	52.31
								49.39
	Euro VI	29.47	0.41	0.07	8.82	8.28	0.78	47.84
Trucks (>12t-14t)	80ties	34.66	18.48	0.07	8.82	9.74	0.78	72.55
	Euro I	30.71	11.15	0.07	8.82	8.63	0.78	60.17
								59.09
	Euro III	31.21	8.19	0.07	8.82	8.77	0.78	57.85
								55.18
	Euro IV SCR	30.22	4.11	0.07	8.82	8.49	0.78	52.50
								54.56

Vehicle category	EURO standard	Operation			Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and -vehicles	Energy supply		
	Euro VI	30.92	0.46	0.07	8.82	8.69	0.78	49.75
Trucks (>14t-20t)	80ties	42.00	22.11	0.07	11.97	11.61	0.86	88.62
								71.67
	Euro II	34.61	13.47	0.07	11.97	9.57	0.86	70.55
								69.06
	Euro IV EGR	35.8	6.61	0.07	11.97	9.90	0.86	65.22
								62.09
	Euro V EGR	36.41	5.06	0.07	11.97	10.07	0.86	64.45
								60.74
	Euro VI	35.45	0.63	0.07	11.97	9.80	0.86	58.78
Trucks (>20t-26t)	80ties	49.18	23.01	0.07	11.97	13.60	0.86	98.68
	Euro I	42.81	16.18	0.07	11.97	11.84	0.86	83.72
								82.81
	Euro III	43.46	12.3	0.07	11.97	12.02	0.86	80.68
								75.71
	Euro IV SCR	41.29	6.00	0.07	11.97	11.42	0.86	71.61
								74.71
	Euro V SCR	41.61	4.09	0.07	11.97	11.51	0.86	70.11
								67.60
Trucks (>26t-28t)	Euro I	44.65	16.90	0.07	11.97	12.35	0.86	86.80
								86.61
	Euro III	46.03	12.65	0.07	11.97	12.73	0.86	84.31

Vehicle category	EURO standard	Operation			Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and -vehicles	Energy supply		
	Euro IV SCR	43.89	6.21	0.07	11.97	12.13	0.86	75.14
								78.18
	Euro V SCR	44.03	4.22	0.07	11.97	12.17	0.86	73.32
								70.81
Trucks (>28t-32t)	Euro I	52.02	19.51	0.07	11.97	13.78	0.86	98.22
								97.42
	Euro III	53.12	14.38	0.07	11.97	14.08	0.86	94.47
								89.64
	Euro IV SCR	51.35	6.99	0.07	11.97	13.61	0.86	84.85
								88.48
	Euro V SCR	51.63	4.65	0.07	11.97	13.68	0.86	82.87
								80.20
Trucks (>32t)	Euro I	51.29	19.43	0.07	11.97	13.59	0.86	97.21
								96.31
	Euro III	51.98	14.75	0.07	11.97	13.77	0.86	93.41
								87.98
	Euro IV SCR	49.99	6.81	0.07	11.97	13.25	0.86	82.95
								86.82
	Euro V SCR	50.40	4.55	0.07	11.97	13.36	0.86	81.22
								78.29
Road trains/semitrailers (>20-28t)	80ties	48.63	22.71	0.07	11.97	12.89	0.86	97.13

Vehicle category	EURO standard	Operation			Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and -vehicles	Energy supply		
	Euro II	42.03	15.88	0.07	11.97	11.14	0.86	81.95
	Euro III	43.59	11.86	0.07	11.97	11.55	0.86	79.90
	Euro IV EGR	43.44	7.98	0.07	11.97	11.51	0.86	75.84
								71.96
	Euro V EGR	44.18	5.98	0.07	11.97	11.71	0.86	74.76
								70.23
	Euro VI	42.95	0.62	0.07	11.97	11.38	0.86	67.86
								101.30
	Euro I	45.45	16.87	0.07	11.97	12.04	0.86	87.27
								85.65
	Euro III	45.93	12.44	0.07	11.97	12.17	0.86	83.45
								79.12
	Euro IV SCR	44.36	6.12	0.07	11.97	11.76	0.86	75.14
								78.15
	Euro V SCR	44.8	4.02	0.07	11.97	11.87	0.86	73.59
								71.01
Road trains/semitrailers (>34-40t)	80ties	57.98	27.12	0.07	16.89	15.36	1.07	118.5
								101.49
	Euro II	50.19	19.17	0.07	16.89	13.30	1.07	100.69
								97.79
	Euro IV EGR	51.23	9.66	0.07	16.89	13.57	1.07	92.49

		Operation			Pre-processes		Land consumption and fragmentation	Total
Vehicle category	EURO standard	Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure and - vehicles	Energy supply		
	Euro V EGR	52.41	7.23	0.07	16.89	13.89	1.07	91.57
	Euro V SCR	50.18	4.66	0.07	16.89	13.30	1.07	86.18
	Euro VI	50.89	0.68	0.07	16.89	13.49	1.07	83.09

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: Calculations by INFRAS as part of the research project.

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