Methodological Convention 3.0 for the Assessment of Environmental Costs

Cost Rates

Version 02/2019

Für Mensch & Umwelt

Umwelt Bundesamt

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by

Dr. Astrid Matthey

German Environment Agency, Dessau Roßlau

Dr. Björn Bünger

German Environment Agency, Dessau Roßlau

on the basis of the findings of the research project "Methodological Convention 3.0 – Further Development and Extension of the Methodological Convention for Estimating Environmental Costs"

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Publisher
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Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
info@umweltbundesamt.de
Internet: www.umweltbundesamt.de

/umweltbundesamt.de
/umweltbundesamt

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Introductory remarks

The cost rates shown in the following chapters are based on the findings of the research project "Methodological Convention 3.0 - Further Development and Extension of the Methodological Convention 2.0 for Estimating Environmental Costs" as well as own research of the UBA. Detailed information regarding the data and methods used can be found in the progress papers which have been drawn up as part of the research project. These are available on request (Astrid.Matthey@uba.de; Bjoern.Buenger@uba.de).

The cost rates shown are averages for emissions in Germany which can, however, also have an effect abroad. This is particularly the case for damage caused by greenhouse gas emissions. Emissions of classic air pollutants and noise cause costs of varying levels depending on the emission situation. If the costs for specific local conditions are to be estimated, the cost rates should therefore be adapted if possible to the relevant circumstances. Averages can then only provide an approximation.

1 Valuation of climate damage: cost rates for carbon dioxide and other greenhouse gas emissions

We recommend using a cost rate of 180 $€_{2016}$ / t $CO_{2\,eq}$ for 2016. Since damage caused by climate change spans various generations, we recommend a sensitivity analysis with a value of 640 $€_{2016}$ / t $CO_{2\,eq}$, as this reflects an equal weighting of the benefits of today's and future generations.[1]

Table 1: UBA recommendation on climate costs in $€_{2016}$ / t $CO_{2\,eq}$

	Climate costs in $€_{2016}$ / t $CO_{2\,eq}$		
	2016	**2030**	**2050**
1% pure rate of time preference	180	205	240
0% pure rate of time preference	640	670	730

Source: Own presentation.

- In order to use cost rates for years for which no values are indicated in Table 1, we recommend interpolating linearly between the indicated cost rates.
- In order to adjust the cost rates to future price levels, we recommend using the consumer price index of the Federal Statistical Office.
- In order to transfer the cost rates from carbon dioxide to other greenhouse gases, we recommend using the greenhouse gas potential (Global Warming Potential (GWP), with a time horizon of 100 years). For CH_4 (methane), this corresponds to 25 times the rate for $CO_{2\,eq}$ costs, and for N_2O (laughing gas) this corresponds to 298 times the rate for $CO_{2\,eq}$ costs[2]. The cost rates for all of the other greenhouse gases are calculated in the same way.
- In order to transfer the cost rates to greenhouse gas emissions in the aviation sector, we recommend using an emission weighting factor of 2. This takes account of the fact that high-altitude emissions have a greater damage potential.[3]

The recommendations of Table 1 follow the damage costs approach and are based on the model in Anthoff (2007) with the following specifications[4]:

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

1 A pure rate of time preference of 1% means, for example, that only 74% of the damage incurred by the next generation (in 30 years) is being taken into account, and only 55% of the damage which will be incurred by the next but one generation (in 60 years) is being taken into account. At a pure rate of time preference of 0%, however, today's damage and future damage are given equal weighting.

2 Cf. IPCC (2007)

3 Cf. ifeu / INFRAS / LBST (2016)

4 Cf. also Bachmann (2018)

- Use of the German consumer price index of the Federal Statistical Office in order to adjust prices from 2010 to 2016 (factor 1.07)[5];
- Use of the purchasing power parities of the World Bank for currency conversions from USD into EUR[6].

Background:

New scientific findings on climate damage costs have been published since the publication of Methodological Convention 2.0. An overview of these findings shows that the damage costs 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 Chap. 3.1 in the volume "Methods" of Methodological Convention 3.0).

The damage cost rates found in the literature vary considerably. For the purposes of erring on the conservative side, the recommended cost rates continue to be based on the FUND damage cost model (Version 3.0, Anthoff 2007) used in Methodological Convention 2.0, the findings of which are in the lower region of the damage cost estimates in the literature (cf. for example Moore and Diaz 2015, Gillingham et al. 2015, which find significantly higher cost rates). The recommended value of 180 $€_{2016}$ / t $CO_{2\ eq}$ is close to the value of 173.5 $€_{2016}$ / t CO_2 determined in the 5th Assessment Report of the IPCC[7].

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 of the cost rates of the Methodological Convention pursue the first-mentioned goal of assessing the damage in monetary values which society incurs due to environmental impacts. The damage costs approach corresponds to this goal. It is therefore used to determine the cost rates of the Methodological Convention including the climate cost rates.

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 been arguing in favour of using equity weighting to take equal account of the welfare effects on all humans since the first Methodological Convention in 2007. If the damage from greenhouse gases emitted in Germany iis to be estimated, global damage must therefore be weighted with the respective ratio of average income (see *Equity Weighting* box). If the modelling data are not available for the German average income, the modelling data for the average income which comes closest to the German value are to be used accordingly. In

5 Destatis (2018)

6 World Bank (2018)

7 IPCC (2014), p. 691, Average of all available studies with a 1% pure time preference rate and different assumptions regarding Equity Weighting, compounded for 2016, currency conversion via purchasing parities of the World Bank.

Anthoff's 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, because of 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 serious. 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.

2 Cost rates for air pollutants

2.1 Average cost rates for air pollutants

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 cannot therefore be used to assess the cost rates.

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

In order to allocate the cost rates 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 cost rates for a wide range of applications.

Table 2 shows the average environmental costs per emitted tonne of the respective pollutant[8] for emissions from "unknown sources"[9] in Germany. These averages can be used for a rough estimate of the damage costs of air pollutants if no specific information is available on the emission sources.

Table 2: Average environmental costs of air pollution due to emissions from an unknown source (in €$_{2016}$ / t emission)

€$_{2016}$/t emission	Cost rates for emissions in Germany				
	Health damage	Biodiversity losses	Crop damage	Material damage	**Total**
Germany total					
$PM_{2.5}$	58,400	0	0	0	**58,400**
PM_{coarse}	960	0	0	0	**960**
PM_{10}	41,200	0	0	0	**41,200**

[8] The main air pollutants in this context are particulates (PM), nitrogen oxides (NOx), sulphur dioxide (SO2), non-methane volatile organic carbon (NMVOC), and ammonia (NH_3).

[9] Here, unknown sources (unknown height of release) means that no details are available on the height of the chimney of the respective facility. The figures are therefore averages. Emissions from low sources (facilities with low chimney heights) give rise to higher costs; emissions from higher sources result in correspondingly lower costs.

	Cost rates for emissions in Germany				
NO_X	14,400	2,600	800	130	**17,930**
SO_2	13,600	1,000	-160	600	**15,040**
NMVOC	1,100	0	950	0	**2,050**
NH_3	21,700	10,400	-100	0	**32,000**

Assumption: PM_{10} consists of 70% $PM_{2.5}$ and 30% PM_{coarse}. For NO_x and SO_2, the costs reflect the damages from secondary formation of particulate matter. Source: Van der Kamp et al. (2017).

These and the following figures relate to emissions in the year 2016. In the original sources the costs are given in €$_{2000}$ or €$_{2005}$. To reflect the present value of the euro, price level changes in Germany between 2000 or 2005 and 2016 have been taken into account. We used the Destatis consumer price index to convert the cost rates to €$_{2016}$.[10] Furthermore, it was taken into account that the willingness to pay for avoiding intangible health damage (pain and suffering) increases with the income. To this end, the cost rates 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 the willingness to pay with an increase in income).[11]

In the NEEDS project, environmental cost rates were also determined for other European countries. However, from a scientific perspective, it scarcely brings a gain in information to indicate European averages for cost rates from air pollutant emissions. This is because there are considerable differences in the factors relevant to the valuation between European countries, primarily in the spatial distribution of the population and the emission sources.

2.2 Differentiated cost rates 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 environmental costs per tonne of emissions vary as a function of these factors. This differentiation is primarily relevant for the costs of particulate matter. The cost rates 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 the average cost rates. However, if site-specific valuations are needed or the proportion of particulate matter emissions is relatively high, using differentiated cost rates brings a gain in information.

Table 3 shows the cost rates for Germany. On the one hand, the figures differ depending on the different release heights for power generation (power stations, release height >100m), industrial power generation (20-100m) and small-scale combustion facilities (0-20m). On the other hand, a distinction is also made between emissions in large metropolitan and urban areas.

The figures quoted relate to emissions for the year 2016 and have been converted to €$_{2016}$ using the consumer price index.

[10] The data can be downloaded from https://www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Preise/Verbraucherpreisindizes/Tabellen_/VerbraucherpreiseKategorien.html

[11] The data can be downloaded from http://ec.europa.eu/eurostat/web/national-accounts/data/main-tables

Table 3: Cost rates for the emission of air pollutants from small-scale combustion facilities and combustion processes in industry (in €$_{2016}$ / t emission)

	Health damage											**Material damage**	**Crop damage**	**Biodi-versity losses**
	Power stations	**Combustion processes in industry**					**Small-scale combustion facilities**							
Surroundings		**Unknown**	**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			
$PM_{2.5}$	31,500	64,900	116,100	65,500	80,400	65,500	61,700	110,400	62,300	76,500	62,300	0	0	0
PM_{coarse}	400	1,100	2,000	1,100	1,400	1,100	1,000	1,800	1,000	1,300	1,000	0	0	0
PM_{10}	22,100	45,700	81,900	46,200	56,700	46,200	43,500	77,800	43,900	53,900	43,900	0	0	0
NO_x	11,100	15,200	15,200	15,200	15,200	15,200	15,800	15,800	15,800	15,800	15,800	100	800	2,600
SO_2	12,700	14,500	14,500	14,500	14,500	14,500	14,700	14,700	14,700	14,700	14,700	600	-200	1,000
NMVOC	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	0	1000	0
NH_3	23,700	23,700	23,700	23,700	23,700	23,700	23,600	23,600	23,600	23,600	23,600	0	-100	10,400

The categories "city" and "town" are distinguished by the size of the municipality (city >100,000, 2000<town<100,000). Assumption: PM_{10} consists of 70% $PM_{2.5}$ and 30% PM_{coarse}. This assumption should be adapted if source-specific information regarding the composition is available. For NO_x and SO_2, the costs reflect the damage from secondary formation of particulate matter.

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

2.3 Cost rates for air pollutants from road transport

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 applies particularly to emissions of particulate matter, since the low release heights mean that they are breathed in more by humans and thus have greater effects on health. For this reason, the impacts of these emissions require special attention. In addition, more people are affected by the emissions in urban agglomerations with their higher population density. The cost rates for the different areas therefore have an adjustment factor for the average costs, which reflects the population density of the respective area (urban, suburban, rural).

Table 4: Cost rates for the emission of air pollutants in transport (in $€_{2016}$ / t emission)

	Health damage				Non health-related damage
Surroundings	**Unknown**	**Urban**	**Suburban**	**Rural**	
$PM_{2.5}$	59,700	242,500	70,000	41,100	0
PM_{coarse}	1,000	4,700	1,200	600	0
PM_{10}	6,800	28,500	8,000	4,600	0
NO_x	15,000	15,000	15,000	15,000	3,500
SO_2	14,200	14,200	14,200	14,200	1,400
NMVOC	1,200	1,200	1,200	1,200	1,000
NH_3	23,000	23,000	23,000	23,000	10,300

The categories Urban, Suburban and Rural are distinguished by the 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 reflect the damage from secondary formation of particulate matter.

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

3 Environmental costs of heat and power generation

3.1 Environmental costs of power generation

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

In addition, the emission factors are divided into direct and indirect emissions. Direct emissions relate to the emissions that arise in the course of power generation, i.e. during the operating phase of the individual technology life cycles. Indirect emissions arise during the other phases of the life cycle (construction, maintenance, decommissioning).

Using these emission factors and the environmental costs per tonne of pollutant presented in Chapters 1 and 2, it is possible to calculate the environmental costs for various power generation technologies. By comparing the different costs rates, 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 cost rates merely take account of greenhouse gases and air pollutants. Other environmental impacts such as the adverse impact on ecosystems or changes in land use are only partially taken into account in the cost rates, or not at all.

There are basically two possible methods for assessing the cost rates. On the one hand, a differentiated analysis requires information and assumptions about the locations of the power generation facilities in Germany and the respective air pollutants emitted. On the other hand, information regarding the overall emissions is sufficient for an analysis at national level. As a result, the calculations are easier to follow and also easier to update if new emission factors become available. The differences from the differentiated method described above tend to be small and have no influence on the qualitative conclusions. Therefore, the assessment of the cost rates below is based on the overall emissions, with both direct and indirect emissions being valued with the cost rates 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 cost rates from Chapters 1 and 2.

The environmental costs of Germany's electricity mix are 13.6 €-Cent / kWh_{el} (44.1 €-Cent / kWh_{el} at a cost rate of 640 €/t $CO_{2\ eq}$).

When estimating the environmental costs of nuclear power, there is the problem that the results in the literature show s 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.[12] This approach was already used in the Methodological Convention 2.0.

[12] For a more detailed treatment of this approach, see "Methodological Convention 3.0 - Methods" Chap. 2.5.4

Table 5: Environmental costs of power generation in Germany including upstream value chains in €-Cent$_{2016}$ / kWh$_{el}$

Electricity generation from	Air pollutants	Greenhouse gases (180 €/t$CO_{2\,eq}$)	Total environmental costs (180 €/t$CO_{2\,eq}$)	Total environmental costs (sensitivity analysis with 640 €/t$CO_{2\,eq}$)
Fossil energy sources				
Lignite	1.95	18.86	20.81	69.01
Coal	1.60	17.19	18.79	62.72
Natural gas	0.83	7.77	8.59	28.44
Oil	4.92	15.13	20.06	58.73
Renewable energy sources				
Hydro power	0.06	0.24	0.30	0.91
Wind energy*	0.10	0.18	0.28	0.65
Photovoltaic systems	0.41	1.23	1.64	4.78
Biomass**	3.74	4.42	7.71	19.46

* Average weighted by production shares from onshore and offshore wind energy;
** Average weighted by production shares for solid, liquid and gaseous biomass.

Source: Own presentation based on Bachmann / van der Kamp (2018) and own calculations.

3.2 Environmental costs of heat generation

The approach for assessing the environmental costs of heat production is the same as that for power generation. Here again, the German Environment Agency provides emission factors for the direct and indirect emissions for each energy source. In order to assess the environmental costs, these are subsequently weighted with the Germany-wide average cost rates (for the respective release height and area). If a site-specific valuation is required, the differentiated costs rates from Chapters 1 and 2 should be used.

Table 6: Environmental costs of heat generation of the households in Germany in €-Cent2016 / $kWh_{final\ energy}$

Heat generation using	Air pollutants	Greenhouse gases (180 €/tCO_{2eq})	Total environmental costs (180 €/tCO_{2eq})	Total environmental costs (sensitivity analysis with 640 €/tCO_{2eq})
Fossil energy sources				
Heating oil	0.82	5.73	6.54	21.18
Natural gas	0.39	4.48	4.87	16.32
Lignite (briquettes)	3.97	7.70	11.67	31.34
District heating with grid losses*	1.30	5.71	7.02	21.62
Electric heating with grid losses**	1.66	10.93	12.59	40.52
Renewable energy sources				
Solar thermal	0.20	0.22	0.41	0.97
Shallow geothermal energy	0.70	3.61	4.31	13.53
Deep geothermal energy	0.01	0.01	0.02	0.05
Biomass**	2.13	0.60	2.74	4.28

* The cost rates vary in some cases considerably depending on the heat source.

** This is based on the average rate for power generation (including renewable energy sources and taking account of upstream value chains for the production of the relevant fuels.

***Average weighted by production shares for gaseous, liquid and solid biomass.

Source: Own presentation based on Bachmann / van der Kamp (2018) and own calculations.

4 Environmental costs of passenger and freight transport in Germany[13]

The assessment of the environmental costs of passenger and freight transport in Germany is divided into two parts. The first step is to assess the emissions from operation of the different vehicle types that arise from fuel combustion, abrasion and suspension. Then the emissions from the other life-cycle phases are estimated, e.g. construction, maintenance and waste management, and fuel supply logistics.

In addition to air pollutant emissions and greenhouse gas emissions, transport also causes noise and further adverse impacts on nature and landscape, primarily because of landscape fragmentation and soil sealing due to the 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 cost rates are described below.

4.1 Assumptions for emission calculations

Emission-induced adverse impacts on the environment and health are greater in cities than in rural areas or on motorways due to the different population density. In order to estimate transport-related cost rates (e.g. costs per vehicle kilometre), it is therefore necessary to assess the relevant emissions (e.g. per vehicle kilometre) and the breakdown of mileage between urban and rural areas, and on motorways. The mileage percentages (Table 7) correspond to the figures from the TREMOD model (Transport Emission Model) used by the German Environment Agency.

Table 7: Breakdown of mileage in road transport (urban, rural, motorway) by vehicle category

Vehicle type	Urban	Rural	Motorway
Cars	26%	41%	33%
Light commercial vehicles	44%	27%	29%
Heavy goods vehicles	14%	25%	61%
Motorcycles	39%	52%	9%
Local buses	57%	37%	6%
Long-distance buses	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 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, and for the greenhouse gases CH_4, CO_2 and N_2O.

[13] Modified version, February 11, 2019. The current version corrects errors in tables 17 and 18 of the version of October 2018. The corrections concern data on utilisation rates of heavy goods vehicles, freight trains and air freight. In addition, cost rates have been updated with newly available data.

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

Furthermore, the calculations of the cost rates for road and rail transport emissions in Germany are performed both for the average fleet of the individual vehicle types and for the Euronorm categories (Euro 0 to Euro VI) for each of these vehicle types and their sub-classes.

Greenhouse gas emissions in the aviation sector take place, for the majority of the flight path covered, at high altitudes and have a greater environmental impact there. In order to reflect this, the environmental costs of the greenhouse gases emitted during airline operations are therefore multiplied by a factor of 2 (see the corresponding recommendation in the chapter on greenhouse gas emissions).

Cost of construction, maintenance and waste management phase of the vehicles

These phases use data from the life-cycle assessment inventory ecoinvent 3.3. The emission factors were calculated from the figures in Spielmann et al. (2007) for overall emissions and the total mileage of the individual vehicle types.[14]

Fuel supply

The calculation of the emissions due to fuel supply also uses the emission factors from TREMOD.[15]

4.2 Cost rates for damage due to land use change and fragmentation

In order to assess the environmental costs caused by loss and fragmentation of natural habitats, the calculations of the study "Externe Effekte des Verkehrs 2015" of the Swiss Federal Office for Spatial Development were used. These factors are illustrated in Table 8 below.

The cost rates are based on the replacement costs approach: In the case of habitat losses, this is based on the costs for (virtually) restoring lost biotope or ecosystem areas. In the case of habitat fragmentation, this is based on the costs for (virtually) constructing defragmentation structures.[16]

Motorways, A-roads, state roads and district roads were considered for road transport. Rail transport was based on train paths. The land use for air transport was inferred from the statistic "Flächenerhebung nach Art der tatsächlichen Nutzung" of the Federal Statistical Office[17].

Table 8: Figures for environmental costs of road transport due to land use and fragmentation, in €-Cent$_{2016}$ per vehicle kilometre

Vehicle category	Costs due to land use and fragmentation [€-Cent$_{2016}$/vehicle km]
Cars	0.34

[14] The processes considered can be seen from Spielmann et al. (2007): "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."
[15] In order to calculate the emissions due to the fuel supply, the processes "market for diesel" and "market for petrol" from the ecoinvent database were used. These processes already include all of the transport routes of the fuels.
[16] Cf. INFRAS/Ecoplan (2018), p. 79 in conjunction with Ecoplan/INFRAS (2014), p. 18.
[17] Cf. Destatis (2017).

Vehicle category	Costs due to land use and fragmentation [€-Cent$_{2016}$/vehicle km]
Buses	0.81
Motorcycle, 2-stroke	0.11
Motorcycle, 4-stroke	0.15
Passenger train, local train	39.65
Passenger train, long-distance	59.48
Passenger air transport (short haul and medium haul; <2,000 km)	8.56
Passenger air transport (long haul; > 2,000 km)	15.71
Light commercial vehicle	0.36
Heavy goods vehicle <7,5t	0.41
Heavy goods vehicle 7,5-14t	0.75
Heavy goods vehicle 14-28t	0.81
Heavy goods vehicle: trailer 28-40t	1.02
Freight train	123.92
Freight air transport	25.91

The cost rates for air transport proportionally account for belly freight.
Source: INFRAS (2018), Umweltkosten Verkehr, Excel tool.

4.3 Cost rates for noise

In densely populated and congested Germany, large 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. The noise pollution is primarily caused by road, rail and air traffic. Cost rates are established below for traffic noise. In doing so, 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 for emissions of air pollutants.

The health costs caused by traffic noise are shown differentiated by level classes. A distinction is made between road, rail and air traffic in order to take proper account of the acoustic properties and the resulting noise effects of these modes of transport.

The cost rates indicated in Table 9 can be used, for example, in order to monetize the consequences of a change in the noise situation caused by noise reduction measures. It should be borne in mind that these are averages. Noise measurements and investigations on site are required in order to more accurately determine the effects.

Table 9: Cost functions for noise effects based on L_{DEN} values

	Cost functions by categories (€/pers.a)												Total costs (€ /pers.a)		
	Intangible costs - YLD			Intangible cost - YLL			Costs Healthcare system			Costs Productio losses			All categories		
dB(A)	Road	Rail	Air	Road	Rail	Air	Road	Rail	Air	Road	Rail	Air	Road	Rail	Air
Overall result for annoyances (excluding self-reported sleep disturbances)															
35-39	0.00	0.00	0.00										0.00	0.00	0.00
40-44	0.00	0.00	0.00										0.00	0.00	0.00
45-49	27.98	8.93	29.39										27.98	8.93	29.39
50-54	56.22	19.67	81.63										56.22	19.67	81.63
55-59	93.64	38.76	155.88										93.64	38.76	155.88
60-64	149.15	72.74	251.31										149.15	72.74	251.31
65-69	231.67	128.14	367.10										231.67	128.14	367.10
70-74	350.10	211.51	502.40										350.10	211.51	502.40
>= 75	513.35	329.37	656.39										513.35	329.37	656.39
Overall results on physical health															
45-49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00
50-54	0.11	0.08	0.05	0.22	0.18	0.17	0.94	0.11	0.84	0.04	0.01	0.02	1.31	0.38	1.08
55-59	0.53	0.38	0.29	1.40	1.10	1.05	3.68	0.53	3.09	0.18	0.04	0.09	5.79	2.05	4.52
60-64	1.26	0.93	0.91	3.54	2.74	3.19	7.41	1.61	6.53	0.42	0.10	0.31	12.63	5.39	10.94
65-69	2.28	1.76	2.22	5.76	4.46	7.10	12.15	3.72	12.67	0.71	0.22	0.92	20.90	10.16	22.91

	Cost functions by categories (€/pers.a)												Total costs (€ /pers.a)		
70-74	3.46	2.76	4.02	8.03	6.23	12.37	17.51	6.43	20.73	1.03	0.37	1.84	30.03	15.80	38.96
>= 75	4.64	3.76	5.82	10.30	8.00	17.64	22.87	9.14	28.79	1.35	0.52	2.75	39.16	21.43	55.01
Overall results for adverse effetcs to cognitive and mental health															
45-49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50-54	1.45	1.43	1.05	0.16	0.15	0.00	0.21	0.20	0.00	0.14	0.14	0.00	1.96	1.92	1.05
55-59	8.62	8.53	6.66	0.77	0.73	0.00	1.00	0.95	0.00	0.70	0.66	0.00	11.08	10.87	6.66
60-64	20.26	20.09	17.09	1.38	1.31	0.14	1.79	1.71	0.18	1.25	1.19	0.12	24.68	24.29	17.53
65-69	31.91	31.66	29.06	1.98	1.89	0.87	2.59	2.46	1.14	1.80	1.71	0.79	38.28	37.72	31.86
70-74	43.55	43.23	42.53	2.59	2.47	2.19	3.38	3.21	2.86	2.35	2.24	1.99	51.88	51.15	49.57
>= 75	55.20	54.80	56.00	3.20	3.05	3.52	4.17	3.97	4.58	2.90	2.76	3.19	65.47	64.57	67.28
Overall results across all end points (excluding self-reported sleep disturbances)															
35-39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40-44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45-49	27.98	8.93	29.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.98	8.93	29.39
50-54	57.79	21.19	82.73	0.38	0.33	0.17	1.15	0.30	0.84	0.18	0.14	0.02	59.50	21.97	83.76
55-59	102.79	47.67	162.82	2.17	1.83	1.05	4.68	1.48	3.09	0.88	0.70	0.09	110.52	51.68	167.05
60-64	170.68	93.77	269.31	4.92	4.05	3.33	9.20	3.32	6.71	1.67	1.29	0.43	186.46	102.42	279.78
65-69	265.85	161.57	398.37	7.75	6.35	7.97	14.74	6.18	13.81	2.51	1.93	1.71	290.85	176.02	421.86
70-74	397.11	257.50	548.95	10.63	8.70	14.57	20.89	9.64	23.59	3.38	2.61	3.83	432.01	278.45	590.93
>= 75	573.19	387.93	718.21	13.50	11.05	21.16	27.04	13.11	33.37	4.26	3.28	5.94	617.99	415.37	778.68

LDEN = Day-Evening-Night Noise Level; Source: Progress paper on noise.

Furthermore, costs can be specified for the traffic noise pollution suffered by the population in Germany. To this end, the findings of the noise mapping in the EU Environmental Noise Directive are used. The current findings of the noise mapping for 2017 are shown in Table 10. The table shows the number of persons who were affected by the individual modes of traffic in the reference year 2016. These figures were blended with cost functions indicated in Table 9. The findings are also shown in Table 10.

Table 10: Traffic noise pollution suffered by the population in pursuance of the EU Environmental Noise Directive and the resulting healthcare costs (reference year: 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 [€]	441,537,644	461,096,788	490,749,215	276,726,095	40,366,624
Healthcare costs due to rail traffic noise [€]	216,747,179	187,142,715	130,021,072	68,440,116	39,959,678
Healthcare costs due to air traffic noise [€]	101,481,040	58,548,042	13,185,650	2,217,891	0

Source: Noise mapping and own calculations.

Consequently, healthcare costs totalling €1.68 billion were incurred in Germany for 2016 due to road traffic noise, €642 million due to rail traffic noise and €174 million due to air traffic noise.

4.4 Cost rates for transport-related activities

Linking the emission factors for the individual vehicle categories and distinguishing between urban and rural areas and motorways (on the basis of the distribution described above) and between operating and other life-cycle phases results in the transport cost rates in €-Cent$_{2016}$ per vehicle kilometre shown in Table 11.

It is true that mileage-related noise cost rates (in € per vehicle kilometre, per passenger kilometre or 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, a noise-related toll cost rate can be deduced, for example, which could then be charged per kilometre driven. However, a monetary valuation of the noise effects of any mileage-related measures or of the transport development is not possible with this cost rate. For example, the construction of a bypass will normally result in an increase in the vehicle kilometres, but at the same time can reduce noise pollution. Likewise, a decline in annual traffic (in vehicle km) all over Germany does not necessarily go hand in hand with lower noise pollution, since it may be the case, for example, that traffic in thinly populated areas has reduced significantly, but has increased in densely populated areas or at night-time when it is a particular nuisance. No mileage-related noise cost rates are therefore calculated[18] in the Methodological Convention 3.0. Nevertheless, in order to stress that environmental costs are also incurred by traffic-related noise, the relevant columns in the tables are identified as nominal amounts with asterisks (***).

[18] In order to compare variants between two measures or alternative paths, the local spatial and time distribution of the sources, propagation conditions and recipients are to be modelled and the resulting noise pollution is to be calculated. This can be evaluated with the relevant exposure-effect functions and, if necessary, the exposure-related noise cost rates of the Methodological Convention.

Table 11: Environmental costs per vehicle kilometre (average for all roads) for different vehicle types in Germany in €-Cent$_{2016}$ / vehicle km

		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**	2.75	0.30	0.03	***	2.06	0.94	0.34	6.42
Car	**Diesel**	2.36	1.49	0.03	***	2.35	0.96	0.34	7.53
Car	**Electric**	0.00	0.00	0.03	***	3.15	2.59	0.34	6.10
Small motorcycle	**Petrol**	1.43	0.71	0.01	***	2.07	0.59	0.11	4.93
Motorcycle	**Petrol**	1.79	0.54	0.01	***	2.21	1.00	0.15	5.70
Local bus	**Diesel**	18.87	10.77	0.15	***	4.81	5.91	0.81	41.30
Long-distance bus	**Diesel**	12.64	8.65	0.09	***	6.03	4.44	0.81	32.65
Passenger train, long-distance	**Electric**	0.00	0.00	0.65	***	201.50	219.01	59.48	480.64
Passenger train, local train	**Weighted Av.**	17.53	20.52	0.33	***	59.13	89.36	39.65	226.54
Passenger air transport, Short-haul and medium-haul		460.92	241.54	---	***	20.01	140.36	8.56	871.39
Passenger air transport, Long-haul		764.51	435.00	---	***	22.43	232.92	15.71	1,470.57
Light commercial vehicle	**Petrol**	2.82	0.60	0.03	***	1.66	1.10	0.36	6.56
Light commercial vehicle	**Diesel**	2.36	1.99	0.03	***	1.82	1.18	0.36	7.73

		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**		
Light commercial vehicle	**Electric**	0.00	0.00	0.03	***	2.83	4.81	0.36	8.02
Heavy goods vehicle ‹7.5t	**Diesel**	5.67	2.29	0.07	***	2.42	2.82	0.41	13.67
Heavy goods vehicle 7.5-14t	**Diesel**	7.76	2.60	0.07	***	3.59	3.34	0.75	18.11
Heavy goods vehicle 14-28t	**Diesel**	10.55	3.25	0.07	***	4.92	4.37	0.81	23.97
Heavy goods vehicle: Trailer 28-40t	**Diesel**	13.38	3.20	0.07	***	6.93	4.99	1.02	29.58
Freight train	**Weighted Av.**	16.59	24.30	0.77	***	276.72	198.74	123.92	641.05
Freight air transport		984.89	582.04	---	***	22.10	299.32	25.91	1,914.27
Motor vessels (inland waterways transport)		503.98	887.70	---	***	602.69	141.57	---	2,135.94
Water craft assemblies (inland waterways transport)		916.76	1,632.19	---	***	1,105.54	278.12	---	3,932.62

Weighted Av. = Weighted Average Electric/Diesel.
The cost rates for air transport proportionally account for belly freight.
Source: Emission factors for direct emissions are taken from HBEFA v3.3 and Tremod; emission factors for indirect emissions are taken from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS.

Table 12: Environmental costs per vehicle kilometre (motorway) for different vehicle types in Germany in €-Cent$_{2016}$ / vehicle km

		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	3.15	0.39	0.02	***	2.06	0.94	0.34	6.90
Car	Diesel	2.41	1.85	0.02	***	2.35	0.96	0.34	7.94
Car	Electric	0.00	0.00	0.02	***	3.15	2.59	0.34	6.09
Small motorcycle	Petrol	2.20	1.08	0.01	***	2.07	0.59	0.11	6.06
Motorcycle	Petrol	2.31	1.29	0.01	***	2.21	1.00	0.15	6.97
Local bus	Diesel	12.71	5.80	0.04	***	4.81	5.91	0.81	30.07
Long-distance bus	Diesel	12.06	7.49	0.04	***	6.03	4.44	0.81	30.87
Light commercial vehicle	Petrol	2.95	0.69	0.02	***	1.66	1.10	0.36	6.79
Light commercial vehicle	Diesel	2,41	2,89	0,02	***	1,82	1,18	0,36	8,68
Light commercial vehicle	Electric	0,00	0,00	0,02	***	2,83	4,81	0,36	8,02
Heavy goods vehicle <7.5t	Diesel	5.84	2.23	0.04	***	2.42	2.82	0.41	13.75
Heavy goods vehicle 7.5-14t	Diesel	7.87	2.42	0.04	***	3.59	3.34	0.75	18.01

Vehicle category	Emission concept	Operation				Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infrastructure and vehicles	Energy supply		
Heavy goods vehicle 14-28t	**Diesel**	10.40	2.52	0.04	***	4.92	4.37	0.81	23.06
Heavy goods vehicle: trailer 28-40t	**Diesel**	12.93	2.72	0.04	***	6.93	4.99	1.02	28.62

Source: Emission factors for direct emissions are taken from HBEFA v3.3 and Tremod; emission factors for indirect emissions are taken from Tremod, Ecoinvent 3.3 and Mobitool. Calculations by INFRAS.

Table 13: Environmental costs per vehicle kilometre (rural) for different vehicle types in Germany in €-Cent$_{2016}$ / vehicle km

Vehicle category	Emission concept	Operation				Pre-processese		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infrastructure and vehicles	Energy supply		
Car	**Petrol**	2.31	0.28	0.02	***	2.06	0.94	0.34	5.94
Car	**Diesel**	2.04	1.21	0.02	***	2.35	0.96	0.34	6.92
Car	**Electric**	0.00	0.00	0.02	***	3.15	2.59	0.34	6.09
Small motorcycle	**Petrol**	1.38	0.68	0.00	***	2.07	0.59	0.11	4.84
Motorcycle	**Petrol**	1.67	0.51	0.00	***	2.21	1.00	0.15	5.55
Local bus	**Diesel**	16.34	7.60	0.06	***	4.81	5.91	0.81	35.52
Long-distance bus	**Diesel**	12.13	8.09	0.06	***	6.03	4.44	0.81	31.55
Passenger train, long distance	**Electric**	0.00	0.00	0.65	***	201.50	219.01	59.48	480.43

Vehicle category	Emission concept	Operation				Pre-processese		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infrastructure and vehicles	Energy supply		
Passenger train, local train	**Weighted Av.**	17.53	20.30	0.23	***	59.13	89.36	39.65	226.20
Light commercial vehicle	**Petrol**	2.43	0.53	0.01	***	1.66	1.10	0.36	6.10
Light commercial vehicle	**Diesel**	2.04	1.73	0.01	***	1.82	1.18	0.36	7.14
Light commercial vehicle	**Electric**	0.00	0.00	0.01	***	2.83	4.81	0.36	8.01
Heavy goods vehicle ‹7.5t	**Diesel**	5.29	2.10	0.05	***	2.42	2.82	0.41	13.07
Heavy goods vehicle 7.5-14t	**Diesel**	7.31	2.35	0.05	***	3.59	3.34	0.75	17.39
Heavy goods vehicle 14-28t	**Diesel**	10.25	3.24	0.05	***	4.92	4.37	0.81	23.64
Heavy goods vehicle: trailer 28-40t	**Diesel**	13.32	3.32	0.05	***	6.93	4.99	1.02	29.62
Freight train	**Weighted Av.**	16.59	23.92	0.52	***	276.72	198.74	123.92	640.42

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

Table 14: Environmental costs per vehicle kilometre (urban) for different vehicle types in Germany in €-Cent$_{2016}$ / vehicle km

		Operation				Pre-processes		Land consumption and fragmentation	Total
Vehicle category	Emission concept	Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infra-structure and vehicles	Energy supply		
Car	**Petrol**	2.94	0.26	0.10	***	2.06	0.94	0.34	6.64
Car	**Diesel**	2.71	1.60	0.10	***	2.35	0.96	0.34	8.07
Car	**Electric**	0.00	0.00	0.10	***	3.15	2.59	0.34	6.17
Small motorcycle	**Petrol**	1.30	0.65	0.03	***	2.07	0.59	0.11	4.75
Motorcycle	**Petrol**	1.83	0.36	0.03	***	2.21	1.00	0.15	5.57
Local bus	**Diesel**	21.03	13.89	0.82	***	4.81	5.91	0.81	47.26
Long-distance bus	**Diesel**	17.42	16.86	0.82	***	6.03	4.44	0.81	46.38
Passenger train, long-distance	**Electric**	0.00	0.00	2.71	***	201.50	219.01	59.48	482.70
Passenger train, local train	**Weighted Av.**	17.53	22.73	1.38	***	59.13	89.36	39.65	229.79
Light commercial vehicle	**Petrol**	2.96	0.60	0.10	***	1.66	1.10	0.36	6.77
Light commercial vehicle	**Diesel**	2.71	1.95	0.10	***	1.82	1.18	0.36	8.11
Light commercial vehicle	**Electric**	0.00	0.00	0.10	***	2.83	4.81	0.36	8.10
Heavy goods vehicle ‹7.5t	**Diesel**	5.17	3.61	0.76	***	2.42	2.82	0.41	15.18

Vehicle category	Emission concept	Operation				Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Noise	Infra-structure and vehicles	Energy supply		
Heavy goods vehicle 7.5-14t	**Diesel**	8.21	5.02	0.76	***	3.59	3.34	0.75	21.67
Heavy goods vehicle 14-28t	**Diesel**	13.04	7.84	0.76	***	4.92	4.37	0.81	31.75
Heavy goods vehicle: trailer 28-40t	**Diesel**	17.87	8.10	0.76	***	6.93	4.99	1.02	39.67
Freight train	**Weighted Av.**	16.59	28.00	3.22	***	276.72	198.74	123.92	647.20

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

Table 15 shows the Euronorm cost rates for the different vehicle types.[19] Within the different vehicle types, an additional breakdown is made on the basis of payload, and an additional category for heavy truck-trailer combinations is included. To make the table easier to read, the cost rates calculated for construction, maintenance, waste management and fuel supply and the damage to nature and landscape caused by highway construction are summarised in the category "Life cycle".

[19] The differentiation of the emission factors in pursuance of Euronorms is based on HBEFA v3.3.

Table 15: Transport cost rates: differentiated by emission category (Euronorm) for the various vehicle types in €-Cent$_{2016}$ / vehicle km

Vehicle category	EURO-Norm	Operation			Pre-processes		Land consump-tion and fragmen-tation	Total
		Green-house gases	Air pollu-tants Ex-haust	Air pollu-tants Ab-rasion	Infra-struct-ure und vehicles	Energy supply		
Car, diesel	**Euro 0**	2.80	1.74	0.03	2.35	1.14	0.34	8.40
	Euro 1	3.06	1.85	0.03	2.35	1.25	0.34	8.88
	Euro 2	2.89	1.80	0.03	2.35	1.18	0.34	8.58
	Euro 3	2.66	1.69	0.03	2.35	1.09	0.34	8.15
	Euro 4	2.53	1.32	0.03	2.35	1.03	0.34	7.60
	Euro 5	2.30	1.73	0.03	2.35	0.94	0.34	7.69
	Euro 6	2.16	0.98	0.03	2.35	0.88	0.34	6.73
Car, petrol	**Euro 0**	3.93	2.32	0.03	2.06	1.50	0.34	10.18
	Euro 1	3.57	1.88	0.03	2.06	1.36	0.34	9.23
	Euro 2	3.44	1.21	0.03	2.06	1.32	0.34	8.39
	Euro 3	3.18	0.28	0.03	2.06	1.23	0.34	7.11
	Euro 4	2.86	0.27	0.03	2.06	1.10	0.34	6.65
	Euro 5	2.55	0.19	0.03	2.06	0.99	0.34	6.15
	Euro 6	2.40	0.19	0.03	2.06	0.93	0.34	5.94
Motorcycle (petrol, 2-stroke)	**Euro 0**	2.06	1.54	0.01	2.07	0.85	0.11	6.64
	Euro 1	2.14	0.76	0.01	2.07	0.89	0.11	5.98
	Euro 2	1.69	0.45	0.01	2.07	0.70	0.11	5.03
	Euro 3	1.38	0.33	0.01	2.07	0.57	0.11	4.47
Motorcycle (petrol, 4-stroke)	**Euro 0**	1.93	0.85	0.01	2.21	1.08	0.15	6.23
	Euro 1	1.83	0.69	0.01	2.21	1.02	0.15	5.90
	Euro 2	1.69	0.59	0.01	2.21	0.94	0.15	5.59
	Euro 3	1.75	0.35	0.01	2.21	0.98	0.15	5.44
Light commercial vehicle (petrol)	**Euro 0**	4.10	4.23	0.03	1.66	1.60	0.36	11.98
	Euro 1	3.64	2.81	0.03	1.66	1.42	0.36	9.91

Vehicle category	EURO-Norm	Operation			Pre-processes		Land consump-tion and fragmen-tation	Total
		Green-house gases	Air pollu-tants Ex-haust	Air pollu-tants Ab-rasion	Infra-struct-ure und vehicles	Energy supply		
	Euro 2	3.24	1.35	0.03	1.66	1.26	0.36	7.90
	Euro 3	3.25	0.31	0.03	1.66	1.26	0.36	6.87
	Euro 4	2.81	0.25	0.03	1.66	1.09	0.36	6.20
	Euro 5	2.51	0.18	0.03	1.66	0.98	0.36	5.71
	Euro 6	2.24	0.17	0.03	1.66	0.87	0.36	5.33
Light commercial vehicle (diesel)	**Euro 0**	5.05	4.85	0.03	1.82	1.84	0.36	13.94
	Euro 1	4.63	3.99	0.03	1.82	1.68	0.36	12.51
	Euro 2	4.15	3.30	0.03	1.82	1.51	0.36	11.16
	Euro 3	3.41	2.63	0.03	1.82	1.24	0.36	9.48
	Euro 4	3.24	1.97	0.03	1.82	1.18	0.36	8.59
	Euro 5	3.01	1.68	0.03	1.82	1.09	0.36	7.98
	Euro 6	2.79	0.58	0.03	1.82	1.02	0.36	6.59
Local bus	**Euro 0**	18.81	34.58	0.15	4.81	5.89	0.81	65.05
	Euro 1	16.31	21.24	0.15	4.81	5.11	0.81	48.42
	Euro 2	16.45	21.38	0.15	4.81	5.15	0.81	48.75
	Euro 3	18.13	18.57	0.15	4.81	5.68	0.81	48.14
	Euro 4	18.89	12.42	0.15	4.81	5.91	0.81	42.99
	Euro 5	19.46	9.11	0.15	4.81	6.09	0.81	40.43
	Euro 6	19.16	0.72	0.15	4.81	6.00	0.81	31.64
Long-distance bus	**Euro 0**	13.20	21.96	0.09	6.03	4.64	0.81	46.72
	Euro 1	12.24	16.43	0.09	6.03	4.30	0.81	39.90
	Euro 2	11.64	16.09	0.09	6.03	4.09	0.81	38.74
	Euro 3	12.37	12.81	0.09	6.03	4.34	0.81	36.45
	Euro 4	12.40	8.07	0.09	6.03	4.36	0.81	31.76
	Euro 5	12.94	5.94	0.09	6.03	4.54	0.81	30.34
	Euro 6	13.09	0.76	0.09	6.03	4.60	0.81	25.37
Heavy goods vehicle (<= 7.5t)	**80ties**	6.45	10.36	0.07	3.59	3.21	0.75	24.43
	Euro I	5.58	7.09	0.07	3.59	2.77	0.75	19.85

Vehicle category	EURO-Norm	Operation Green-house gases	 Air pollu-tants Ex-haust	 Air pollu-tants Ab-rasion	Pre-processes Infra-struct-ure und vehicles	 Energy supply	Land consump-tion and fragmen-tation	Total
	Euro II	5.41	7.04	0.07	3.59	2.69	0.75	19.54
	Euro III	5.69	5.01	0.07	3.59	2.82	0.75	17.94
	Euro IV EGR	5.78	3.39	0.07	3.59	2.87	0.75	16.45
	Euro IV SCR	5.59	2.59	0.07	3.59	2.78	0.75	15.37
	Euro V EGR	5.85	2.50	0.07	3.59	2.91	0.75	15.67
	Euro V SCR	5.59	1.56	0.07	3.59	2.78	0.75	14.34
	Euro VI	5.67	0.23	0.07	3.59	2.82	0.75	13.13
Heavy goods vehicle (>7.5t-12t)	**80ties**	8.65	16.60	0.07	3.59	3.72	0.75	33.38
	Euro I	7.68	9.92	0.07	3.59	3.31	0.75	25.32
	Euro II	7.46	9.93	0.07	3.59	3.21	0.75	25.01
	Euro III	7.84	7.17	0.07	3.59	3.37	0.75	22.79
	Euro IV EGR	7.90	4.77	0.07	3.59	3.40	0.75	20.47
	Euro IV SCR	7.64	3.76	0.07	3.59	3.29	0.75	19.09
	Euro V EGR	8.00	3.58	0.07	3.59	3.44	0.75	19.42
	Euro V SCR	7.63	2.48	0.07	3.59	3.29	0.75	17.80
	Euro VI	7.77	0.39	0.07	3.59	3.34	0.75	15.91
Heavy goods vehicle (>12t-14t)	**80ties**	9.13	17.55	0.07	3.59	3.93	0.75	35.02
	Euro I	8.09	10.59	0.07	3.59	3.48	0.75	26.58
	Euro II	7.87	10.62	0.07	3.59	3.38	0.75	26.28
	Euro III	8.23	7.78	0.07	3.59	3.54	0.75	23.96
	Euro IV EGR	8.25	5.15	0.07	3.59	3.55	0.75	21.35
	Euro IV SCR	7.96	3.90	0.07	3.59	3.43	0.75	19.71

Vehicle category	EURO-Norm	Operation			Pre-processes		Land consump-tion and fragmen-tation	Total
		Green-house gases	Air pollu-tants Ex-haust	Air pollu-tants Ab-rasion	Infra-struct-ure und vehicles	Energy supply		
	Euro V EGR	8.40	3.84	0.07	3.59	3.62	0.75	20.27
	Euro V SCR	8.01	2.61	0.07	3.59	3.45	0.75	18.48
	Euro VI	8.15	0.44	0.07	3.59	3.51	0.75	16.51
Heavy goods vehicle (>14t-20t)	**80ties**	11.07	21.00	0.07	4.92	4.59	0.81	42.45
	Euro I	9.39	12.61	0.07	4.92	3.89	0.81	31.69
	Euro II	9.12	12.79	0.07	4.92	3.78	0.81	31.49
	Euro III	9.55	9.41	0.07	4.92	3.96	0.81	28.71
	Euro IV EGR	9.44	6.28	0.07	4.92	3.91	0.81	25.43
	Euro IV SCR	9.07	5.01	0.07	4.92	3.76	0.81	23.63
	Euro V EGR	9.60	4.81	0.07	4.92	3.98	0.81	24.18
	Euro V SCR	9.12	3.50	0.07	4.92	3.78	0.81	22.20
	Euro VI	9.34	0.60	0.07	4.92	3.87	0.81	19.61
Heavy goods vehicle (>20t-26t)	**80ties**	12.96	21.85	0.07	4.92	5.37	0.81	45.98
	Euro I	11.28	15.36	0.07	4.92	4.67	0.81	37.12
	Euro II	11.05	15.59	0.07	4.92	4.58	0.81	37.01
	Euro III	11.45	11.68	0.07	4.92	4.75	0.81	33.68
	Euro IV EGR	11.26	7.87	0.07	4.92	4.66	0.81	29.59
	Euro IV SCR	10.88	5.70	0.07	4.92	4.51	0.81	26.89
	Euro V EGR	11.47	5.93	0.07	4.92	4.75	0.81	27.96
	Euro V SCR	10.97	3.89	0.07	4.92	4.54	0.81	25.20
	Euro VI	11.16	0.63	0.07	4.92	4.62	0.81	22.21

Vehicle category	EURO-Norm	Operation: Green-house gases	Operation: Air pollu-tants Ex-haust	Operation: Air pollu-tants Ab-rasion	Pre-processes: Infra-struct-ure und vehicles	Pre-processes: Energy supply	Land consump-tion and fragmen-tation	Total
Heavy goods vehicle (>26t-28t)	Euro I	11.77	16.05	0.07	4.92	4.88	0.81	38.49
	Euro II	11.76	15.90	0.07	4.92	4.87	0.81	38.33
	Euro III	12.13	12.01	0.07	4.92	5.03	0.81	34.97
	Euro IV EGR	11.97	8.09	0.07	4.92	4.96	0.81	30.82
	Euro IV SCR	11.57	5.90	0.07	4.92	4.79	0.81	28.06
	Euro V EGR	12.16	6.05	0.07	4.92	5.04	0.81	29.05
	Euro V SCR	11.60	4.01	0.07	4.92	4.81	0.81	26.22
	Euro VI	11.81	0.65	0.07	4.92	4.89	0.81	23.16
Heavy goods vehicle (>28t-32t)	Euro I	13.71	18.53	0.07	4.92	5.11	0.81	43.15
	Euro II	13.58	18.34	0.07	4.92	5.06	0.81	42.79
	Euro III	14.00	13.65	0.07	4.92	5.22	0.81	38.67
	Euro IV EGR	13.98	9.14	0.07	4.92	5.21	0.81	34.14
	Euro IV SCR	13.53	6.64	0.07	4.92	5.05	0.81	31.02
	Euro V EGR	14.25	6.80	0.07	4.92	5.31	0.81	32.17
	Euro V SCR	13.61	4.41	0.07	4.92	5.07	0.81	28.90
	Euro VI	13.87	0.71	0.07	4.92	5.17	0.81	25.54
Heavy goods vehicles (>32t)	Euro I	13.52	18.45	0.07	4.92	5.04	0.81	42.81
	Euro II	13.30	18.58	0.07	4.92	4.96	0.81	42.64
	Euro III	13.70	14.01	0.07	4.92	5.11	0.81	38.62
	Euro IV EGR	13.58	9.40	0.07	4.92	5.06	0.81	33.84
	Euro IV SCR	13.18	6.46	0.07	4.92	4.91	0.81	30.35

Vehicle category	EURO-Norm	Operation			Pre-processes		Land consumption and fragmentation	Total
		Greenhouse gases	Air pollutants Exhaust	Air pollutants Abrasion	Infrastructure und vehicles	Energy supply		
	Euro V EGR	13.87	6.99	0.07	4.92	5.17	0.81	31.83
	Euro V SCR	13.28	4.33	0.07	4.92	4.95	0.81	28.36
	Euro VI	13.47	0.69	0.07	4.92	5.02	0.81	24.98
Truck-trailer combinations/ articulated lorries (>20-28t)	**80ties**	12.82	21.57	0.07	4.92	4.78	0.81	44.96
	Euro I	11.39	15.27	0.07	4.92	4.25	0.81	36.70
	Euro II	11.08	15.08	0.07	4.92	4.13	0.81	36.09
	Euro III	11.49	11.26	0.07	4.92	4.28	0.81	32.83
	Euro IV EGR	11.45	7.58	0.07	4.92	4.27	0.81	29.10
	Euro IV SCR	11.05	5.72	0.07	4.92	4.12	0.81	26.69
	Euro V EGR	11.64	5.68	0.07	4.92	4.34	0.81	27.46
	Euro V SCR	11.11	3.81	0.07	4.92	4.14	0.81	24.86
	Euro VI	11.32	0.59	0.07	4.92	4.22	0.81	21.93
Truck-trailer combinations/articulated lorries (>28-34t)	**80ties**	13.43	22.71	0.07	4.92	5.01	0.81	46.96
	Euro I	11.98	16.02	0.07	4.92	4.47	0.81	38.27
	Euro II	11.69	15.78	0.07	4.92	4.36	0.81	37.63
	Euro III	12.11	11.81	0.07	4.92	4.51	0.81	34.23
	Euro IV EGR	12.07	7.88	0.07	4.92	4.50	0.81	30.25
	Euro IV SCR	11.69	5.81	0.07	4.92	4.36	0.81	27.66
	Euro V EGR	12.31	5.84	0.07	4.92	4.59	0.81	28.54
	Euro V SCR	11.81	3.82	0.07	4.92	4.40	0.81	25.83
	Euro VI	11.98	0.57	0.07	4.92	4.47	0.81	22.82

Vehicle category	EURO-Norm	Operation			Pre-processes		Land consumption and fragmentation	Total
		Green-house gases	Air pollutants Exhaust	Air pollutants Abrasion	Infra-structure und vehicles	Energy supply		
Truck/trailer combinations/ articulated lorries (>34-40t)	80ties	15.28	25.75	0.07	6.93	5.70	1.02	54.75
	Euro I	13.40	18.18	0.07	6.93	5.00	1.02	44.59
	Euro II	13.23	18.20	0.07	6.93	4.93	1.02	44.38
	Euro III	13.59	13.80	0.07	6.93	5.07	1.02	40.47
	Euro IV EGR	13.50	9.17	0.07	6.93	5.03	1.02	35.72
	Euro IV SCR	13.10	6.66	0.07	6.93	4.88	1.02	32.66
	Euro V EGR	13.81	6.87	0.07	6.93	5.15	1.02	33.85
	Euro V SCR	13.23	4.43	0.07	6.93	4.93	1.02	30.60
	Euro VI	13.41	0.64	0.07	6.93	5.00	1.02	27.07

Source: Calculations by INFRAS.

The average environmental costs per vehicle km are presented inTable 16. In addition the environmental costs for a sensitivity analysis (cost rate for Greenhouse gases 640€ per ton of CO_2) are included in the table.

Table 16: Environmental costs per vehicle kilometre for different vehicle types in Germany in €-Cent$_{2016}$ / vehicle kilometre

Vehicle category		Total environmental costs (GG cost rate 180 EUR/t CO_2eq.)	Sensitivity analysis Total environmental costs (GG cost rate 640 EUR/t CO_2eq.)
Car	Petrol	6.42	17.80
Car	Diesel	7.53	18.29
Car	Electric	6.10	15.57
Small motorcycle	Petrol	4.93	11.69
Motorcycle	Petrol	5.70	15.35
Local bus	Diesel	41.30	107.00
Long-distance bus	Diesel	32.65	81.52
Passenger train, long distance	Electric	480.64	1,203.71
Passenger train, local train	Weighted Av.	226.54	532.63
Passenger air transport, Short-haul and medium-haul		871.39	2,328.49
Passenger air transport, Long-haul		1,470.57	3,870.33
Light commercial vehicle	Petrol	6.56	17.80
Light commercial vehicle	Diesel	7.73	18.14
Light commercial vehicle	Electric	8.02	18.71
Heavy goods vehicle <7.5t	Diesel	13.67	34.52
Heavy goods vehicle 7.5-14t	Diesel	18.11	47.08
Heavy goods vehicle 14-28t	Diesel	23.97	63.29
Heavy goods vehicle: trailer 28-40t	Diesel	29.58	80.35
Freight train	Weighted Av.	641.05	1,464.23
Freight air transport		1,914.27	4,994.93
Motor vessels (inland waterways transport)		2,135.94	3,652.66
Water craft assemblies (inland waterway transport)		3,932.62	6,724.13

Weighted Av. = Weighted Average Diesel/Electric.

The cost rates for air transport proportionally account for belly freight.

Source: Calculations by INFRAS an down calculations.

To make it possible to convert the costs shown per vehicle kilometre for the various vehicle types into cost rates per passenger kilometre (pkm) and tonne kilometre (tkm), information is needed about the utilisation rates for each vehicle type. Here use was made of recommendations by TREMOD 5.8 and for the utilisation rates of trains from Bundesnetzagentur, Marktuntersuchung 2018. This information is summarised in Table 17 below.

Table 17: Utilisation rate per vehicle type

Vehicle types	Passengers / vehicle	Tonnes / vehicles
Cars	1.49	
Small motorcycle	1.02	
Motorcycle	1.11	
Local bus	16.5	
Long-distance bus	30.4	
Passenger train, long distance	276	
Passenger train, local train	81	
Passenger air transport (short and medium-haul)	105	
Passenger air transport (long-haul)	257	
Heavy goods vehicle (<7.5t)		0.94
Heavy goods vehicle (7.5-14t)		1.59
Heavy goods vehicle (14-28t)		3.44
Heavy goods vehicle: 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

Utilisation rates for light commercial vehicles are not available.
The cost rates for air transport proportionally account for belly freight.
Source: TREMOD 5.8 and Bundesnetzagentur, Marktuntersuchung 2018.

Using these factors, it is possible to convert all of the costs specified in vehicle kilometres into passenger kilometres (pkm) or tonne kilometres (tkm). Table 18shows the average environmental costs calculated in this way (for all routes) per passenger kilometre or per tonne kilometre. Since the noise costs are not calculated based on the mileage, the environmental costs are not included here. The environmental costs are in turn calculated separately if the cost rate of 640 EUR/t is used in accordance with a sensitivity analysis for greenhouse gases.

Table 18: Environmental costs per passenger kilometre or tonne kilometre for various vehicle types in Germany in €-Cent$_{2016}$/ Pkm or tkm

Vehicle type		Unit	Total environmental costs (GG cost rate 180 EUR/t CO_2 eq.)	Sensitivity analysis Total environmental costs (GG cost rate 640 EUR/t CO_2 eq.)
Car	Petrol	€-Cent/Pkm	4.30	11.94
Car	Diesel	€-Cent/Pkm	5.05	12.26
Car	Electric	€-Cent/Pkm	4.09	10.44
Small motorcycle	Petrol	€-Cent/Pkm	4.84	11.49
Motorcycle	Petrol	€-Cent/Pkm	5.13	13.83
Local bus	Diesel	€-Cent/Pkm	2.50	6.48
Long-distance bus	Diesel	€-Cent/Pkm	1.07	2.68
Passenger train, long distance	Electric	€-Cent/Pkm	1.74	4.36
Passenger train, local train	Weighted Av.	€-Cent/Pkm	2.80	6.58
Passenger air transport, Short-haul and medium-haul		€-Cent/Pkm	8.33	22.25
Passenger air transport, Long-haul		€-Cent/Pkm	5.73	15.07
Heavy goods vehicle ‹7.5t	Diesel	€-Cent/tkm	14.48	36.56
Heavy good vehicle 7.5-14t	Diesel	€-Cent/tkm	11.39	29.61
Heavy goods vehicle 14-28t	Diesel	€-Cent/tkm	6.96	18.38

Vehicle type		Unit	**Total environmental costs** (GG cost rate 180 EUR/t CO_2 eq.)	**Sensitivity analysis Total environmental costs** (GG cost rate 640 EUR/t CO_2 eq.)
Heavy goods vehicle: trailer 28-40t	**Diesel**	€-Cent/tkm	2.75	7.47
Freight train	**Weighted Av.**	€-Cent/tkm	1.28	2.93
Freight air transport		€-Cent/tkm	45.52	118.78
Motor vessels (inland waterways transport)		€-Cent/tkm	2.01	3.45
Water craft assemblies (inland waterway transport)		€-Cent/tkm	2.02	3.46

Weighted Av. = Weighted Average Electric/Diesel.
The cost rates for air transport proportionally account for belly freight.
Source: Calculations by INFRAS and own calculations.

5 List of References

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

Bachmann, T. M. (2018): Umweltkosten durch Treibhausgasemissionen, Sachstandspapier zur Methodenkonvention 3.0., Umweltbundesamt, Juli 2018.

Bachmann, T. M., van der Kamp, J. (2018): Umweltkosten der Strom- und Wärmeerzeugung, Sachstandspapier zur Methodenkonvention 3.0., Umweltbundesamt, September 2018.

Bieler, C., Sutter, D. (2018): Umweltkosten des Verkehrs in Deutschland, Sachstandspapier zur Methodenkonvention 3.0., Umweltbundesamt, September 2018.

Destatis (2017), Land- und Forstwirtschaft, Fischerei - Bodenfläche nach Art der tatsächlichen Nutzung, Fachserie 3 Reihe 5.1 – 2016.

Destatis (2018): Verbraucherpreise, https://www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Preise/Verbraucherpreisindizes/Tabellen_/VerbraucherpreiseKategorien.html?cms_gtp=145110_slot%253D2, abgerufen am 19.2.2018.

Doll, C., Sutter, D. (2018): Umweltkosten durch Lärm, Sachstandspapier zur Methodenkonvention 3.0., Umweltbundesamt, September 2018.

Ecoplan/INFRAS (2014), Externe Effekte des Verkehrs 2010 - Monetarisierung von Umwelt-, Unfall- und Gesundheitseffekten; Auftraggeber: Bundesamt für Raumentwicklung; Bern, Zürich und Altdorf.

Gillingham, K., Nordhaus, W., Anthoff, D., Blandford, G., Bosetti, V., Christensen, P., McJeon, H., Reilly, J., Sztorc, P. (2015): Modeling Uncertainty in Climate Change: A Multi-Model Comparison. Cambridge, MA, National Bureau of Economic Research (NBER).

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

ifeu / INFRAS / LBST (2016): Klimaschutzbeitrag des Verkehrs bis 2050. UBA-Texte 56/2016; Dessau -Roßlau.

INFRAS/Ecoplan (2018), Externe Effekte des Verkehrs 2015 - Aktualisierung der Berechnungen von Umwelt-, Unfall- und Gesundheitseffekten des Strassen-, Schienen-, Luft- und Schiffsverkehrs 2010 bis 2015, Auftraggeber: Bundesamt für Raumentwicklung ARE, Zürich und Bern.

IPCC (2007): Climate Change 2007: Working Group I: The Physical Science Basis, https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html , abgerufen 5.9.2018.

IPCC (2014a): Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and sectoral aspects. Working Group II contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, United Kingdom and New York, NY, USA, Cambridge University Press.

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

Moore, F. C., D. B. Diaz (2015): Temperature impacts on economic growth warrant stringent mitigation policy. Nature Clim. Change 5(2): 127-131.

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

van der Kamp, J., Bachmann, T. M., Preiss, P., Sutter, D., Bieler, C. (2017): Umweltkosten durch Luftschadstoffemissionen, Sachstandspapier zur Methodenkonvention 3.0., Umweltbundesamt, Dezember 2017.

Weltbank (2018): Purchasing power parities, https://data.worldbank.org/indicator/PA.NUS.PRVT.PP.05?locations=DE&view=chart, abgerufen am 19.2.2018.

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

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