BEST-PRACTICE COST RATES FOR AIR POLLUTANTS, TRANSPORT, POWER GENERATION AND HEAT GENERATION

Annex B to "Economic Valuation of Environmental Damage – Methodological Convention 2.0 for Estimates of Environmental Costs"

Umwelt Bundesamt

Imprint

Publisher: German Federal Environment Agency (UBA)
Press Office
PO Box 1406, 06813 Dessau
E-Mail: pressestelle@uba.de
Internet: www.umweltbundesamt.de

Date: August 2012, updated February 2014

Editorial: Section I 1.4 -
Economic and Social Environmental Issues, Sustainable Consumption

Authors: Sylvia Schwermer (UBA)
Philipp Preiss, Wolf Müller (IER)

Assisted by:
Veronika Wille, Jutta Reumann-Schwichtenberg, Katrin Ohlau, Sandra Torras Ortiz, Peter Fantke, Rainer Friedrich (IER)
Markus Maibach, Daniel Sutter (Infras)

Edited: Sylvia Schwermer

Translation: Terence J. Oliver

Layout: UBA

Cover photo: © Wrangler / Fotolia.de

Annex B is essentially based on the results of UFOPLAN project 3708 14 101 “Schätzung externer Umweltkosten und Vorschläge zur Kosteninternalisierung in ausgewählten Politikfeldern” (Estimation of Environmental Externalities and Proposals for Internalising Costs in Selected Policy Areas), edited by the IER (Institut für Energiewirtschaft und rationelle Energieanwendung) and Infras, Zürich.

Contents

B 1 Introduction

Soundly based information for estimating environmental costs is of great interest for environmental policy. It provides information which helps to bring greater objectivity to discussions about the costs and benefits of environmental protection, and which contributes to the design of tools for protecting the environment. Economic valuation of environmental damage makes it possible to estimate the economic benefits of environmental policy measures. This is important because environmental policy measures avoid environmental and health costs now and in the future.

A qualified assessment of the validity of such estimates is of great importance for the usability of estimates of environmental costs. In 2007 the Federal Environment Agency therefore drew up a "Methodological Convention for Estimating External Environmental Costs". The convention contains procedural suggestions and recommendations about important assumptions for estimating environmental costs (e.g. in relation to discounting, dealing with risks and uncertainties, and valuation approaches and methods). For a number of cost categories (costs due to air pollution and climate impact damage and derived costs for power generation, transport costs), best-practice cost rates have been developed on the basis of the UBA Methodological Convention.[1]

In 2009, to take account of recent research findings on the estimation of environmental externalities, the Federal Environment Agency commissioned the IER (Institut für Energiewirtschaft und rationelle Energieanwendung, Stuttgart) and the research institute Infras, Zürich, to carry out the research project "Estimation of Environmental Externalities and Proposals for Internalising Environmental Costs in Selected Policy Areas". The research project was partly concerned with reviewing and updating the Methodological Convention in the light of the latest scientific developments. The results are documented in progress papers.[2]

This annex to the "Methodological Convention" contains the UBA recommendations on best-practice cost rates for climate and air pollutants and the estimates based on them for activity-specific environmental costs of transport and of heat and power generation. The recommendations are based to a large extent on the findings of the research project. Reasons are given for further assumptions or value judgements by the Federal Environment Agency. All recommendations are based on euro figures for 2010 (€$_{2010}$).

---

[1] Cf. Maibach et al. (2007) "Praktische Anwendung der Methodenkonvention: Möglichkeiten der Berücksichtigung externer Umweltkosten bei Wirtschaftlichkeitsrechnungen öffentlicher Investitionen", downloadable from http://www.umweltdaten.de/publikationen/fpdf-l/3194.pdf and the Federal Environment Agency's background paper "Externe Kosten kennen – Umwelt besser schützen", downloadable from http://www.umweltbundesamt.de/uba-info-presse/hintergrund/externekosten.pdf .

[2] Links to the progress papers can be found in the Bibliography under Wille/Preiss/Friedrich (2012), Preiss et al. (2012) and Ohlau/Preiss/Friedrich (2012).

B 2 Valuation of climate impact damage: Cost rates for carbon dioxide and other greenhouse gas emissions

Based on the overview of existing damage and avoidance costs and following the principle of erring on the conservative side, we consider a best-practice cost rate of 80 €$_{2010}$ / tonne (t) CO_2 to be appropriate.

Table B1: UBA recommendation on climate costs in €$_{2010}$ / t CO_2

	Climate costs in €$_{2010}$ / t CO_2		
	Short term 2010	**Medium term 2030**	**Long term 2050**
Minimum figure	40	70	130
Average figure	80	145	260
Maximum figure	120	215	390

- We recommend using the figure of 80 €$_{2010}$ / t CO_2 as the central cost rate.
- We consider sensitivity analyses in the range 40 € / t CO_2 to 120 € / t CO_2 to be meaningful.
- A distinction should be made between short, medium and long-term cost rates, since the damage costs and also the avoidance costs increase in the course of time.
- The cost rates for the greenhouse gases CH_4 and N_2O are calculated in the same way as the global warming potential, i.e. the costs for CH_4 are 25 times the rate for CO_2 costs, and the costs for N_2O are 298 times the rate for CO_2.[3]
- Greenhouse gas emissions in the aviation sector are multiplied by an emission weighting factor of two. This is due to the fact that high-altitude emissions have a greater damage potential.

<u>The reasons:</u>

Both damage costs and avoidance costs are used to estimate the cost rate for carbon dioxide emissions. In its progress paper "Treibhausgase – Klimawandel" (Wille et al. 2012), the IER has evaluated the findings of existing studies on the damage costs of climate change and the avoidance costs necessary to achieve climate policy objectives.

The IER suggests using the avoidance costs approach[4] to achieve the target of a maximum global warming of two degrees, and arrives at a cost rate of 77€$_{2010}$ / t CO_2. The cost rate

[3] Cf. IPCC (2007a) and Blasing (2012): http://cdiac.ornl.gov/pns/current_ghg.html

[4] The uncertainties arising in the context of global warming when estimating environmental damage are considered too great for the damage costs approach to be used. By contrast, use of the avoidance costs approach is justified – assuming that the two-degree target correctly reflects the population's preferences. Wille et al. (2012), p. 7f.

increases as time goes on, because the cheaper avoidance options are selected first. The recommendation is based on an extensive evaluation of the literature. The avoidance costs recommended are the figures of the meta-study by Kuik et al. (2009) for a target in the region of 450ppm CO_2e. Evaluation of the literature and interpolation leads to the figures in Table B2.

Table B2: IER recommendation on avoidance costs in €$_{2010}$ / t CO_2

	2010	2020	2025	2030	2040	2050
Minimum figure	44	59	68	79	106	143
Average figure	77	104	119	139	186	251
Maximum figure	135	182	211	244	329	442

Source: Wille et al. (2012), based on Kuik et al. (2009), conversion to €$_{2010}$: own calculations.

However, the Federal Environment Agency does not consider it appropriate to use avoidance costs alone as an approximation to climate costs. While avoidance costs are a good indicator of adaptation costs or opportunity costs that have to be borne by the economy to achieve a specific target, they do not give any indication of the extent of the damage. Neither can they be used for cost-benefit analyses.[5] Here it is necessary to fall back on damage costs.

Recent estimates of damage costs show a wide range of variation. In addition to the uncertainties and variations regarding the physical impacts of climate change and their monetary valuation, it is the following key factors in the models that explain the differences in damage cost estimates in the studies:

- the discount rate used,
- the type of weighting for the occurrence of damage in different regions (known as equity weighting; see also the explanation in the box below),
- the way the uncertainty is taken into account (cut-off limits when forming averages)[6].

Since the publication of the Methodological Convention in 2007 the number of variants emerging from the model calculations has increased substantially.

The range of variation can be restricted by adopting certain conventions regarding assumptions, as proposed by the UBA in the first Methodological Convention in 2007.

[5] In this connection see Methodological Convention 2.0, Section 3.2.
[6] Wille et al. (2012).

In the Methodological Convention, the UBA recommends using a low time preference rate (1 percent, sensitivity test 0 percent) and applying equity weighting when estimating long-term or intergenerational impacts. According to the IER analysis, there are signs that a scientific consensus is emerging on the choice of discount rate (1 percent) and the method of eliminating improbable values (1 percent trimmed average calculation)[7]. The damage costs figures shown in Table B3 reflect these assumptions. They originate from the FUND model and were calculated as part of the NEEDS project. They are based on a climate scenario, the “standardised EMF 14” scenario. It assumes emissions ranging from 15-17 Gt C/a in 2050 and 20-26 Gt C/a in 2100. At least until 2080 this corresponds approximately to the IPCC scenario A1 and reflects a moderate business-as-usual scenario.

Table B3: Damage costs with equity weighting in €/t CO_2 and low time preference rate

	2005	2015	2025	2035	2045	2055
Equity Weighting (WEu) Time preference: 0%	416.72	511.97	569.00	509.50	508.33	671.33
Equity Weighting (WEu) Time preference: 1%	111.81	141.23	170.55	158.51	164.96	225.95
Equity Weighting (Av) Time preference: 0%	87.5	103.7	112.7	100.4	101.0	136.7
Equity Weighting (Av) Time preference: 1%	23.5	28.6	33.8	31.2	32.8	46.0

WEu: West European Equity Weighting; Av: Average Equity Weighting
Source: Own presentation, cited after Wille et al. (2012) and Anthoff (2007).

A scrutiny of the range shown here and evaluation of further literature on damage costs reveals that the order of magnitude of the cost rate of 70 $€_{2000}$/t CO_2 so far recommended by the Federal Environment Agency remains valid. To take account of price developments since 2000, recalculating this figure in terms of $€_{2010}$ using German inflation rates would result in a cost rate of 82 €/t CO_2. Adjustment based on the European inflation rate would work out at 89 €/t CO_2. Given certain assumptions, however, such as a time preference rate of 0 percent (see line 1 of Table B3), it is also possible to justify considerably higher figures.

[7] For an explanation of the average calculation, cf. Anthoff (2007) and Wille et al. (2012).

Box: Equity weighting

According to existing scientific findings, poorer regions like Africa, South America and India are currently more badly affected by climate change than the richer countries in medium and northern latitudes.

In economic valuation the differences in prosperity of the regions affected can be taken into account by means of equity weighting in the context of sensitivity analyses. This is based on the justified assumption that each additional euro is of greater value to a poor person than a rich person. Conversely, damage of one euro is considerably more serious for a poor person than for a rich one. This can be illustrated by the following example: Climate change causes assumed damage of 1 € – regardless of the region. If this damage occurs in a poorer country with an average income of 100 € per head, the damage amounts to 1/100 of the per capita income. However, if the same damage occurs in a rich country with an average income of 5000 €, the damage represents only 1/5000 of pro capita income. Thus in relation to income, the damage in the richer country is less serious. Equity weighting means weighting the damage in terms of income equivalents. If the per capita income in a poor country is 50 times less, the costs are weighted 50 times higher. Partly because of the disproportionately high occurrence of environmental damage in poorer regions of the world, the way in which damage and benefits in different regions are aggregated to form a global figure has a crucial influence on the overall amount of damage costs: Equity weighting can magnify the damage costs of climate change by a factor of up to 10.[8]

Weighting of the damage in the different regions may be undertaken in three ways: NoEW (No Equity Weighting) means that the damage costs are entered as their euro values without any weighting. AvEW (Average Equity Weighting) involves adjusting the damage costs in line with average global income, and WeuEW adjusts on the basis of average EU incomes. The cost rates are highest for WeuEW and lowest for NoEW.

In the Methodological Convention 2007, the UBA argued in favour of equity weighting. We advocate using the WeuEW approach, as this corresponds most closely to the "polluter pays" principle. It values the damage costs caused by one tonne of CO_2 as if they were incurred (entirely) in Europe. On the assumption of a low time preference rate (1 percent), using WeuEW and 1 percent trimmed average calculation results in a damage costs estimate for 2010 of around 120 €/t CO_2 (2010). This figure is in the upper third of the results in the overview of existing studies. Using AvEW, the cost rate is around €25.

[8] Cf. Watkiss et al. (2005), who demonstrate this with model calculations and sensitivity analyses.

B 3 Cost rates for air pollutants

B 3.1 Average cost rates for air pollutant emissions[9]

The cost rates for various air pollutants were determined during the EU project NEEDS (New Energy Externalities for Sustainability), which was completed in 2009, and are documented in Preiss et al. (2008).[10] The results represent the latest state of scientific knowledge. Table B4 shows the average environmental costs per emitted tonne of the relevant pollutant[11], for emissions from "unknown sources"[12] in Germany. These average figures can be used for a rough estimate of damage costs due to air pollutants if no site-specific information is available on the emission sources.

Table B4: Average environmental costs of air pollution due to power generation in Germany (in €$_{2010}$ / t emission)

	Cost rates for emissions in Germany				
€$_{2010}$/t emission	Health damage	Biodiversity losses	Crop damage	Material damage	Total
Germany total					
$PM_{2.5}$	55,400	0	0	0	55,400
PM_{coarse}	2,900	0	0	0	2,900
PM_{10}	39,700	0	0	0	39,700
NO_x	12,600	2,200	500	100	15,400
SO_2	11,900	800	-100	500	13,200
NMVOC	1,600	-300	300	0	1,600
NH_3	18,200	8,700	-100	0	26,800

Source: NEEDS, http://www.needs-project.org/docs/RS3a%20D1.1.zip[13]

The figures quoted relate to emissions for the year 2010. In the original sources the costs are stated in €$_{2000}$. To reflect the current value of the Euro, changes in price levels in Germany between 2000 and 2010 were taken into account. To this end, Eurostat inflation data in the

[9] The following remarks are taken from Müller/Preiss (2012).
[10] The documentation of the cost rates recommended in NEEDS can be found in http://www.needs-project.org/docs/RS3a%20D1.1.zip (all figures in €$_{2000}$).
[11] The main air pollutants in this context are particulates (PM), nitrogen oxides (NO_x), sulphur dioxide (SO_2), non-methane volatile organic carbon (NMVOC), and ammonia (NH_3).
[12] Unknown sources (unknown height of release) means that no details are available on the location of the installation (e.g. inside or outside built-up areas) or the height of the chimney. The figures are therefore averages. Emissions from low sources and in densely populated areas give rise to higher costs; emissions from high sources and/or in thinly populated areas result in correspondingly lower costs.
[13] Own recalculation from €$_{2000}$ to €$_{2010}$ on the basis of Eurostat/HVPI, figures rounded. To a small extent, individual areas may give rise to negative external costs.

form of the harmonised consumer price index (HCPI) were used to convert the cost rates to €2010.[14]

Under the NEEDS project, environmental cost rates were also determined for other European countries. In general, the figures for Germany are distinctly higher than the EU-27 average. There are two main reasons for this. Firstly, the population density in Germany is above the average for EU-27, which means that for the same quantity of emissions there are more people affected in Germany and hence greater costs for health damage. Secondly, incomes in Germany are above the average for the EU-27, so willingness to pay for avoiding environmental and health damage is greater.

Table B5 shows the average figures in €2010 that can be used for energy-related air pollutant emissions.

Table B5: Average environmental costs of air pollution due to power generation in EU-27 (in €2010 / t emission)

Air pollutants	Cost rates for emissions in EU-27 in €2010 / t emission
$PM_{2.5}$	40,600
PM_{coarse}	2,800
PM_{10}	29,300
NO_x	10,300
SO_2	10,100
NMVOC	1,500
NH_3	19,100

Source: NEEDS, http://www.needs-project.org/docs/RS3a%20D1.1.zip, own conversion from €2000 to €2010 and weighting of EU cost rates after Müller/Preiss (2012)[15]. Assumption: 70% of PM_{10} consists of $PM_{2.5}$.

B 3.2 Differentiated cost rates for air pollutant emissions from power generation and industrial processes

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 and the environment. 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 primary particulates and dust emissions. The cost rates for other air pollutants show little variation with regard to release height and location.

[14] The data can be downloaded from http://epp.eurostat.ec.europa.eu/portal/page/portal/hicp/data/database

[15] To determine the average it was assumed that 45% of emissions come from small-scale combustion units and industry, and 10% from power stations. It was also assumed that the emission sources were divided into 70% rural and 30% urban areas.

For most applications it is therefore sufficient to use the average cost rates. However, where it is a matter of site-specific valuations or where the proportion of particulate emissions is relatively high, using differentiated cost rates brings a gain in information.

Table B6 shows the differentiated cost rates for Germany and the EU-27. 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 processes (3-20m). A distinction is also made between emissions in urban and rural areas.

The figures quoted relate to emissions for the year 2010 and have been converted to €$_{2010}$ using the consumer price index.[16]

Table B6: Costs of air pollution due to power generation and industrial processes in Germany and the EU-27 (in €$_{2010}$ / t)

	Cost rates for emissions in Germany		Cost rates for emissions in EU-27	
€$_{2010}$/ t emission	Urban (average)	Rural	Urban (average)	Rural
$PM_{2.5}$ (power station)	30,600	30,600	18,600	18,600
PM_{coarse} (power station)	1,200	1,200	700	700
PM_{10} (power station)	21,800	21,800	13,200	13,200
$PM_{2.5}$ (industry)	56,000	55,400	33,500	33,000
PM_{coarse} (industry)	3,200	2,900	2,100	1,900
PM_{10} (industry)	40,100	39,700	24,100	23,700
$PM_{2.5}$ (small-scale)	127,200	58,500	85,000	39,200
$PM_{2.5}$ (small-scale)	11,400	2,900	8,600	2,200
PM_{10} (small-scale)	92,500	41,800	62,100	28,100
NO_X (power station)	12,300	12,300	8,000	8,000
NO_X (industry/small-scale)	15,400	15,400	10,500	10,500
SO_2 (power station)	12,400	12,400	9,200	9,200
SO_2 (industry/small-scale)	13,200	13,200	10,100	10,100
NMVOC	1,700	1,700	1,500	1,500
NH_3	26,800	26,800	19,100	19,100

Sources: NEEDS (Preiss et al., 2008) and EXIOPOL (Müller et al., 2010), figures rounded. Assumption: 70% of PM_{10} consists of $PM_{2.5}$.

[16] There are plans for a further revision of cost rates using new concentration response factors (CRF) for the classic air pollutants from the EU projects HEIMTSA (Health and Environment Integrated Methodology and Toolbox for Scenario Assessment) and INTARESE (Integrated Assessment of Health Risks of Environmental Stressors in Europe) (Friedrich et al., 2011). However, these results have not all been published yet, and for this reason they are not shown here.

B 3.3 Cost rates for air pollutants from road traffic

Emissions from road traffic 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 fine particulates, 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.

Table B7 shows the different cost rates for emissions in Germany and in the EU-27. The cost rates for SO_2, NO_x, NMVOC and NH_3 correspond to the cost rates for energy-related emission at low release heights (Table B6). The valuation of fine particulates from road traffic is based on the work of Torras Ortiz (2010)[17].

Table B7: Cost rates for air pollutant emissions from road traffic in Germany and the EU-27 (in €$_{2010}$ / t)

		Cost rates for emissions in Germany €$_{2010}$ / t		Cost rates for emissions in EU-27	
Emission		Urban (average)	Rural	Urban (average)	Rural
$PM_{2.5}$	exhaust	364,100	122,800	392,600	81,400
PM_{coarse}	abrasion, suspension	10,200	2,900	11,000	3,100
PM_{coarse}	abrasion, suspension*	33,700	11,000	36,300	8,500
NOx	construction and operation phase	15,400	15,400	10,300	10,300
SO_2	construction and operation phase	13,200	13,200	10,100	10,100
NMVOC	construction and operation phase	1,700	1,700	1,500	1,500
NH_3	construction and operation phase	26,800	26,800	19,100	19,100
*: PM_{10} emissions due to abrasion and suspension consist of 10% $PM_{2.5}$ and 90% PM_{coarse}. Here the cost rate for exhaust emissions without the toxicity factor of 1.5 for combustion engine emissions is used as the valuation basis for $PM_{2.5}$.					

Sources: Fine particulates results from Torras (2010) and HEIMTSA (Friedrich et al., 2011), costs due to other pollutants from NEEDS (Preiss et al., 2008) and EXIOPOL (Müller et al., 2010), figures rounded.

With regard to the factors shown for $PM_{2.5}$ emissions due to road traffic, it should be noted that these include a mark-up by a factor of 1.5 on the damage due to combustion engine emissions. This was recommended in the methodological update to the ExternE project series (ExternE, 2005) and also in the first version of the Methodological Convention.

[17] Torras Ortiz (2010) takes account of the new dose-response relationships from the EU projects HEIMTSA and INTARESE (Friedrich et al., 2011). Cf. the details in the progress paper “Klassische Luftschadstoffe” (Preiss et al., 2012).

The figures relate to emissions for the year 2010. In the original sources the cost rates are given in euro for the year 2000 ($€_{2000}$). To approximately reflect the present value of the euro, price level changes in Germany and Europe between 2000 and 2010 have been taken into account. To this end, Eurostat inflation data in the form of the harmonised consumer price index (HCPI) were used to convert the cost rates to $€_{2010}$.

B 4 Environmental costs of rail and road traffic in Germany

The determination of cost rates for the environmental costs of road and rail traffic in Germany is divided into two parts. The first step is to determine 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, traffic also causes noise and adverse impacts on nature and landscape. Cost estimates exist for 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.

B 4.1 Assumptions for emission calculations

Emission-induced adverse impacts on environment and health are greater in cities than in rural areas. In order to estimate transport-related cost rates (e.g. costs per vehicle kilometre), it is therefore necessary to determine the relevant emissions (e.g. per vehicle kilometre) and the breakdown of mileage between urban and rural areas. The mileage percentages for urban and rural areas (Table B8) correspond to the figures from the TREMOD model (Transport Emission Model) used by the Federal Environment Agency.

Table B8: Breakdown of PM emissions due to road transport into urban and rural sources by vehicle category

Vehicle type	Urban	Rural
Cars	38%	62%
Light commercial vehicles	49%	51%
Heavy goods vehicles	26%	74%
Motorcycles	28%	72%
Local buses	72%	28%
Long-distance buses	23%	77%
Bus fleet (assumption)	40%	60%
Rail traffic (assumption)	20%	80%

Source: IFEU (2010) and own estimates.

The emission factors used to determine the cost rates for passenger and goods train and for motorcycles are taken from the TREMOVE transport model (De Ceuster et al., 2007). The data relate to vehicle kilometres travelled in 2010. However, since only an average emission factor for each pollutant was available for rail traffic, an assumption was made about activities in urban and rural areas. It was assumed that 20 percent of rail traffic takes place in urban and 80 percent in rural areas. In the absence of available data, an assumption was also necessary for the urban/rural breakdown of mileage of the entire bus fleet. This can also be seen from the table.

Emission factors from the “Handbuch für Emissionsfaktoren aus dem Straßenverkehr” (Road Traffic Emission Factor Handbook) (HBEFA 3.1, 2010) were used to determine the emissions from the operating phase of vehicles.[18] The HBEFA provides emission factors for 2005 and 2010 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. However, only the emission factors for 2010 were used to calculate the cost rates shown here.

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

[18] Special licence provisions apply to commercial users of the handbook. The documentation on the HBEFA 3.1 will shortly be available at www.hbefa.net.

Subdivision by the various exhaust emission standards Euro 0 to Euro V is possible for the following vehicle types:

- Private cars: Diesel engine and petrol engine
- Light commercial vehicles: Diesel engine and petrol engine
- Heavy goods vehicles (HGV): Diesel engine, 7.5t/7.5t–12t/12t–14t/14t–20t/20t–26t/26t–28t/28t–32t/>32t
- (Heavy) truck-trailer combinations: Diesel engine, 20t–28t/28t–34t/34t–40t
- Local buses: Diesel engine
- Long-distance buses: Diesel engine
- Motorcycles: 2-stroke and 4-stroke

Some of the HBEFA emission factors are considerably increased compared with the previous versions. Since the reasons for this are very varied, they are not discussed or described in detail here.[19] The emissions factors for the year 2010 are used for all Euronorm stages. The factors for determining costs due to abrasion and suspension were determined by Kugler (2012).

The calculation of the cost rates for the other life-cycle phases is broken down into a number of different areas.

Cost of construction, maintenance and waste management phase

These phases use data from the life-cycle assessment inventory ecoinvent 2.0. 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.[20]

Fuel supply

The calculation of the emissions due to fuel supply also uses the emission factors from the life-cycle assessment inventory ecoinvent 2.0.[21] Since the figures from the ecoinvent database are stated in kg emission per kg fuel, it was necessary to convert them to kg emission per vehicle kilometre. This conversion was performed using the density of the two fuels (diesel and petrol) and the consumption figures in litres per vehicle kilometre by vehicle types. The consumption figures are taken from the TREMOVE database (Table B9). The calculations shown here are based on the emission factors for the year 2010.

[19] Cf. Kugler et al. (2010).

[20] 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."

[21] The calculation of fuel supply emissions was made using the ecoinvent 2.0 processes "petrol, unleaded, at refinery" and "petrol, unleaded, at regional storage" for petrol (gasoline) production and the processes "diesel, at refinery" and "diesel, at regional storage" for diesel production.

Table B9: Fuel consumption figures per vehicle kilometre for different vehicle types

Vehicle category	Fuel	Litres / 100 vehicle kilometres	
		2005	2010
Cars	Petrol	8.18	7.65
Cars	Diesel	6.05	5.95
Light commercial	Petrol	8.72	8.35
Light commercial	Diesel	9.75	8.82
Long-distance buses	Diesel	28.57	28.87
Local buses	Diesel	40.48	42.97
Motorcycles	Petrol (4-stroke)	4.60	4.57
Motorcycles	Petrol (2-stroke)	2.71	2.61
Motorcycles	Petrol (weighted average)	4.03	3.92
HGV	Diesel	27.64	27.37

Source: Underlying data: De Ceuster et al. (2007).

B.4.2 Cost rates for damage to nature and landscape

In a recent study by INFRAS the cost rates for nature and landscape were calculated in €-cent$_{2008}$.[22] These factors are shown in Table B10 below.

[22] The study is a revision of the UIC study by INFRAS/IWW (2004). This new study has not yet been published. The figure were provided by Sutter (2011).

Table B10: Figures for environmental costs due to road and rail transport for nature and landscape, in €-cent$_{2008}$ per vehicle kilometre

Vehicle category	Costs for nature and landscape [€-cent$_{2008}$/vehicle kilometre]
Cars	0.08
Buses	0.17
Motorcycles	0.04
Light commercial vehicles	0.12
Heavy goods vehicles	0.4
Freight and passenger trains	1.9

Source: Sutter (2011).

B 4.3 Cost rates for noise

The assumptions for the valuation of damage due to traffic noise are described in detail in the IER progress paper on noise (Ohlau et al., 2012).

If the prime concern is an overall estimate of noise costs (i.e. not differentiated by traffic volume and time of day), average costs per vehicle type should be used instead of marginal costs. To date, however, calculation of average costs with the aid of impact pathway analysis has not yet been performed. If the intention is nevertheless to determine the magnitude of average costs, IER recommends using the upper limit of marginal costs per vehicle kilometre.[23]

[23] Regarding the problems of using marginal costs in the valuation of noise costs, cf. the Methodological Convention 2.0, Chapter 3.3.

Table B11: Marginal costs of noise in €-cent2010/vehicle kilometre for road and rail transport

	Time of day	Urban (€-cent2010/vehicle km) Range	Low population density (€-cent2010/vehicle km) Range
Cars	Day	0.79 – 1.94	0.04 – 0.13
	Night	1.45 – 3.53	0.08 – 0.23
Motorcycle	Day	1.60 – 3.87	0.09 – 0.25
	Night	2.91 – 7.05	0.17 – 0.46
Local buses	Day	3.99 – 9.68	0.22 – 0.62
	Night	7.27 – 17.61	0.41 – 1.15
Light trucks	Day	3.99 – 9.68	0.22 – 0.62
	Night	7.27 – 17.61	0.41 – 1.15
Heavy trucks	Day	7.33 – 17.78	0.41 – 1.15
	Night	13.37 – 32.41	0.75 – 2.09
Passenger train	Day	24.74 – 48.88	10.91 – 21.56
	Night	81.58 – 161.19	35.99 – 71.11
Freight train	Day	43.86 – 105.82	21.54 – 41.73
	Night	178.93 – 431.73	70.82 – 170.88

Source: CE Delft (2008) and own calculations.

Table B12: Recommendation on average costs of noise in €-cent$_{2010}$/vehicle kilometre for road and rail transport

	Time of day	Urban (€-cent$_{2010}$/vehicle km)
Cars	Day	1.94
	Night	3.53
Motorcycle	Day	3.87
	Night	7.05
Local buses	Day	9.68
	Night	17.61
Light trucks	Day	9.68
	Night	17.61
Heavy trucks	Day	17.78
	Night	32.41
Passenger train	Day	48.88
	Night	161.19
Freight train	Day	105.82
	Night	431.73

Source: CE Delft (2008) and own calculations.

B.4.4 Cost rates for transport-related activities

Linking the emission factors for the individual vehicle categories and distinguishing between urban and rural areas (on the basis of the distribution described above) and between operating and other life-cycle phases results in the transport cost rates shown in Table B13 in €-cent$_{2010}$ per vehicle kilometre travelled. The costs for noise correspond to a daytime situation with high traffic density.

Table B13: Environmental costs for various vehicle types in Germany in €-cent2010 / vehicle kilometre

Cost rates, transport [€-cent2010/vehicle kilometre]		Urban: Exhaust GG	Urban: Exhaust non-GG	Urban: Abrasion	Urban: Noise	Urban: Construction, maintenance, waste management	Urban: Fuel supply	Urban: Nature and landscape	Urban: Total	Rural: Exhaust GG	Rural: Exhaust non-GG	Rural: Abrasion	Rural: Noise	Rural: Construction, maintenance, waste management	Rural: Fuel supply	Rural: Nature and landscape	Rural: Total
Cars (Fleet 2010)	Diesel	1.4	1.9	0.3	1.9	0.6	1.6	0.1	7.7	1.0	1.0	0.0	0.0	0.6	1.6	0.1	4.3
	Petrol	1.5	0.5	0.3	1.9	0.6	1.1	0.1	5.9	1.2	0.4	0.0	0.0	0.6	1.1	0.1	3.3
HGVs (Fleet 2010)	Light comm. (diesel)	1.7	4.7	0.3	9.7	0.4	1.8	0.1	18.6	1.6	2.8	0.0	0.0	0.4	1.8	0.1	6.7
	Light comm. (petrol)	1.6	1.2	0.3	9.7	0.4	1.7	0.1	14.9	1.3	0.9	0.0	0.0	0.4	1.7	0.1	4.4
	HGV (diesel)	5.4	12.1	2.7	17.8	0.8	5.4	0.4	44.6	5.1	6.2	0.3	0.0	0.8	5.4	0.4	18.3
Bus (fleet 2010)	Diesel	8.7	26.6	2.7	9.7	1.4	5.1	0.2	54.4	6.2	12.6	0.3	0.0	1.4	5.1	0.2	25.9
Motorcycles (fleet 2010)	MC (petrol, 4-stroke)	0.8	0.8	0.1	3.9	0.0	0.6	0.0	6.2	0.8	0.7	0.0	0.0	0.0	0.6	0.0	2.1
	MC (petrol, 2-stroke)	0.5	1.0	0.1	3.9	0.0	0.8	0.0	6.3	0.6	0.8	0.0	0.0	0.0	0.8	0.0	2.2
Passenger train	Diesel	29.2	248.0		48.9	43.9		1.8	371.8	29.2	153.7		0.0	43.9		1.8	228.6
	Electric	49.7	15.9		48.9	43.9		1.8	160.2	49.7	11.1		0.0	43.9		1.8	106.5
Freight train	Diesel	93.0	789.6		105.8	43.9		1.8	1,034.1	93.0	489.3		0.0	43.9		1.8	628.0
	Electric	98.9	31.7		105.8	43.9		1.8	282.0	98.9	22.1		0.0	43.9		1.8	166.7

Cost rates, transport [€-cent2010/vehicle kilometre]		Motorway: Exhaust GG	Motorway: Exhaust non-GG	Motorway: Abrasion	Motorway: Noise	Motorway: Construction, maintenance, waste management	Motorway: Fuel supply	Motorway: Nature and landscape	Motorway: Total	All routes (average): Exhaust GG	All routes (average): Exhaust non-GG	All routes (average): Abrasion	All routes (average): Noise	All routes (average): Construction, maintenance, waste management	All routes (average): Fuel supply	All routes (average): Nature and landscape	All routes (average): Total
Cars (Fleet 2010)	Diesel	1.2	1.5	0.0	0.0	0.6	1.6	0.1	5.0	1.2	1.5	0.1	0.7	0.6	1.6	0.1	5.8
	Petrol	1.6	0.6	0.0	0.0	0.6	1.1	0.1	4.0	1.4	0.5	0.1	0.7	0.6	1.1	0.1	4.5
HGVs (Fleet 2010)	Light comm. (diesel)	2.0	4.0	0.0	0.0	0.4	1.8	0.1	8.3	1.7	4.0	0.2	4.7	0.4	1.8	0.1	12.9
	Light comm. (petrol)	1.6	1.2	0.0	0.0	0.4	1.7	0.1	5.0	1.5	1.1	0.2	4.7	0.4	1.7	0.1	9.7
	HGV (diesel)	5.6	5.7	0.3	0.0	0.8	5.4	0.4	18.3	5.4	7.5	0.9	4.6	0.8	5.4	0.4	25.1
Bus (fleet 2010)	Diesel	5.6	10.8	0.3	0.0	1.4	5.1	0.2	23.4	7.0	17.6	1.3	4.6	1.4	5.1	0.2	37.3
Motorcycles (fleet 2010)	MC (petrol, 4-stroke)	1.1	1.3	0.0	0.0	0.0	0.6	0.0	3.1	0.9	1.0	0.0	1.1	0.0	0.6	0.0	3.6
	MC (petrol, 2-stroke)	1.0	1.2	0.0	0.0	0.0	0.8	0.0	3.0	0.7	1.0	0.0	1.1	0.0	0.8	0.0	3.7
Passenger train	Diesel									29.2	172.6		9.8	43.9		1.8	257.2
	Electric									49.7	12.1		9.8	43.9		1.8	117.2
Freight train	Diesel									93.0	549.4		21.2	43.9		1.8	709.2
	Electric									98.9	24.0		21.2	43.9		1.8	189.8

Source: Calculations by IER as part of research project.

Table B14 shows the Euronorm cost rates for the different vehicle types. Here the calculations were again performed on the basis of the results of Torras Ortiz (2010) and HEIMTSA recommended in the Methodological Convention. 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". Here too, the factors for noise in a daylight situation with high traffic density apply.

The emission factors used are listed in the section "Supplementary tables on transport emission factors".

Table B14: Transport cost rates: differentiated by emission category (Euronorm) for the various vehicle types in €-cent$_{2010}$ / vehicle kilometre

Vehicle type and emission category		Environmental costs (average of all routes)					
		Exhaust					
[€-cent$_{2010}$/vehicle kilometre]		GG	non-GG	Abrasion	Noise	Life cycle	Total
Car, petrol engine (fleet 2010)	Euro I	1.7	1.7	0.1	0.7	1.8	6.0
	Euro II	1.7	1.2	0.1	0.7	1.8	5.4
	Euro III	1.6	0.3	0.1	0.7	1.8	4.5
	Euro IV	1.5	0.3	0.1	0.7	1.8	4.4
	Euro V	1.4	0.2	0.1	0.7	1.8	4.3
Car, diesel engine (fleet 2010)	Euro 0	1.5	3.5	0.1	0.7	2.3	8.1
	Euro I	1.3	3.6	0.1	0.7	2.3	8.0
	Euro II	1.2	2.8	0.1	0.7	2.3	7.1
	Euro III	1.2	2.0	0.1	0.7	2.3	6.3
	Euro IV	1.2	1.6	0.1	0.7	2.3	5.8
	Euro V	1.1	0.9	0.1	0.7	2.3	5.1
Motorcycles (2-stroke, fleet 2010)	Euro 0	0.9	3.6	0.0	1.1	0.9	6.5
	Euro I	0.8	1.8	0.0	1.1	0.9	4.6
	Euro II	0.7	1.0	0.0	1.1	0.9	3.7
	Euro III	0.6	0.5	0.0	1.1	0.9	3.1

Vehicle type and emission category [€-cent2010/vehicle kilometre]		Environmental costs (average of all routes) Exhaust GG	non-GG	Abrasion	Noise	Life cycle	Total
Motorcycles (4-stroke, fleet 2010)	Euro 0	0.8	1.1	0.0	1.1	0.6	3.6
	Euro I	0.8	1.0	0.0	1.1	0.6	3.5
	Euro II	0.7	0.8	0.0	1.1	0.6	3.2
	Euro III	1.0	0.6	0.0	1.1	0.6	3.3
Local bus (diesel engine, fleet 2010)	Euro 0	8.8	48.3	1.2	4.6	6.8	69.7
	Euro I	7.6	27.6	1.2	4.6	6.8	47.8
	Euro II	7.5	22.6	1.2	4.6	6.8	42.7
	Euro III	7.7	19.1	1.2	4.6	6.8	39.5
	Euro IV	7.5	10.6	1.2	4.6	6.8	30.7
	Euro V	7.7	7.8	1.2	4.6	6.8	28.0
Long-distance bus (diesel engine, fleet 2010)	Euro 0	6.4	23.4	0.7	4.6	6.8	41.9
	Euro I	5.8	17.5	0.7	4.6	6.8	35.3
	Euro II	5.8	15.8	0.7	4.6	6.8	33.7
	Euro III	5.9	12.8	0.7	4.6	6.8	30.8
	Euro IV	5.9	7.2	0.7	4.6	6.8	25.1
	Euro V	6.0	4.9	0.7	4.6	6.8	23.1

Vehicle type and emission category [€-cent2010/vehicle kilometre]		Environmental costs (average of all routes)					
		Exhaust GG	Exhaust non-GG	Abrasion	Noise	Life cycle	Total
Light commercial vehicles (petrol engine, fleet 2010)	Euro 0	2.1	4.1	0.1	4.7	2.2	13.2
	Euro I	2.0	2.8	0.1	4.7	2.2	11.8
	Euro II	1.8	1.6	0.1	4.7	2.2	10.4
	Euro III	1.6	0.4	0.1	4.7	2.2	9.0
	Euro IV	1.5	0.3	0.1	4.7	2.2	8.8
	Euro V	1.1	0.2	0.1	4.7	2.2	8.3
Light commercial vehicles (diesel engine, fleet 2010)	Euro 0	2.3	10.4	0.1	4.7	2.3	19.8
	Euro I	1.9	6.5	0.1	4.7	2.3	15.6
	Euro II	1.6	4.4	0.1	4.7	2.3	13.1
	Euro III	1.4	2.7	0.1	4.7	2.3	11.2
	Euro IV	1.4	2.5	0.1	4.7	2.3	11.0
	Euro V	1.0	1.1	0.1	4.7	2.3	9.2
Heavy goods vehicles (≤7.5t, diesel engine, fleet 2010)	Euro 0	3.0	12.2	0.9	4.6	6.6	27.4
	Euro I	2.6	7.3	0.9	4.6	6.6	22.1
	Euro II	2.5	6.6	0.9	4.6	6.6	21.3
	Euro III	2.7	4.8	0.9	4.6	6.6	19.7
	Euro IV	2.7	2.6	0.9	4.6	6.6	17.4
	Euro V	2.7	1.6	0.9	4.6	6.6	16.5
Heavy goods vehicles (7.5t - 12t, diesel engine, fleet 2010)	Euro 0	4.1	17.1	0.9	4.6	6.6	33.4
	Euro I	3.6	10.3	0.9	4.6	6.6	26.1
	Euro II	3.5	9.3	0.9	4.6	6.6	25.0
	Euro III	3.7	6.9	0.9	4.6	6.6	22.8
	Euro IV	3.6	3.7	0.9	4.6	6.6	19.5
	Euro V	3.7	2.4	0.9	4.6	6.6	18.2
Heavy goods vehicles (12t - 14t, diesel engine, fleet 2010)	Euro 0	4.3	18.1	0.9	4.6	6.6	34.6
	Euro I	3.8	11.0	0.9	4.6	6.6	27.0
	Euro II	3.7	10.0	0.9	4.6	6.6	25.8
	Euro III	3.9	7.5	0.9	4.6	6.6	23.6

Vehicle type and emission category [€-cent2010/vehicle kilometre]		Environmental costs (average of all routes) Exhaust GG	non-GG	Abrasion	Noise	Life cycle	Total
	Euro IV	3.8	3.9	0.9	4.6	6.6	19.9
	Euro V	3.9	2.5	0.9	4.6	6.6	18.6
Heavy goods vehicles (14t- 20t, diesel engine, fleet 2010)	Euro 0	5.2	21.9	0.9	4.6	6.6	39.3
	Euro I	4.4	13.4	0.9	4.6	6.6	29.9
	Euro II	4.3	12.1	0.9	4.6	6.6	28.5
	Euro III	4.5	9.3	0.9	4.6	6.6	26.0
	Euro IV	4.3	4.9	0.9	4.6	6.6	21.4
	Euro V	4.4	3.3	0.9	4.6	6.6	19.8
Heavy goods vehicles (20t - 26t, diesel engine, fleet 2010)	Euro 0	6.1	22.7	0.9	4.6	6.6	41.0
	Euro I	5.7	16.3	0.9	4.6	6.6	34.2
	Euro II	5.2	14.7	0.9	4.6	6.6	32.1
	Euro III	5.4	11.5	0.9	4.6	6.6	29.0
	Euro IV	5.2	5.9	0.9	4.6	6.6	23.2
	Euro V	5.3	3.9	0.9	4.6	6.6	21.3
Heavy goods vehicles (20t - 28t, diesel engine, fleet 2010)	Euro 0	6.4	23.9	0.9	4.6	6.6	42.5
	Euro I	5.6	17.1	0.9	4.6	6.6	34.8
	Euro II	5.5	15.1	0.9	4.6	6.6	32.8
	Euro III	5.7	11.9	0.9	4.6	6.6	29.7
	Euro IV	5.5	6.1	0.9	4.6	6.6	23.8
	Euro V	5.6	4.0	0.9	4.6	6.6	21.7
Heavy goods vehicles (28t - 32t, diesel engine, fleet 2010)	Euro 0	7.3	27.1	0.9	4.6	6.6	46.6
	Euro I	6.4	19.6	0.9	4.6	6.6	38.2
	Euro II	6.4	17.4	0.9	4.6	6.6	35.9
	Euro III	6.6	13.4	0.9	4.6	6.6	32.1
	Euro IV	6.4	6.8	0.9	4.6	6.6	25.5
	Euro V	6.6	4.4	0.9	4.6	6.6	23.2
Heavy goods vehicles (>32t, diesel engine, fleet 2010)	Euro 0	7.2	27.1	0.9	4.6	6.6	46.5
	Euro I	6.3	19.6	0.9	4.6	6.6	38.1
	Euro II	6.2	17.6	0.9	4.6	6.6	36.0

Vehicle type and emission category [€-cent2010/vehicle kilometre]		Environmental costs (average of all routes) Exhaust GG	non-GG	Abrasion	Noise	Life cycle	Total
	Euro III	6.4	13.7	0.9	4.6	6.6	32.3
	Euro IV	6.3	6.8	0.9	4.6	6.6	25.3
	Euro V	6.4	4.5	0.9	4.6	6.6	23.0
Truck-trailer combinations (20t - 28t, diesel engine, fleet 2010)	Euro 0	6.0	22.4	0.9	4.6	6.7	40.6
	Euro I	5.3	16.2	0.9	4.6	6.7	33.8
	Euro II	5.2	14.3	0.9	4.6	6.7	31.7
	Euro III	5.4	11.1	0.9	4.6	6.7	28.7
	Euro IV	5.3	5.7	0.9	4.6	6.7	23.2
	Euro V	5.3	3.8	0.9	4.6	6.7	21.3
Truck-trailer combinations (28t - 34t, diesel engine, fleet 2010)	Euro 0	6.3	23.5	0.9	4.6	6.7	42.0
	Euro I	5.6	17.0	0.9	4.6	6.7	34.8
	Euro II	5.5	15.0	0.9	4.6	6.7	32.7
	Euro III	5.7	11.6	0.9	4.6	6.7	29.5
	Euro IV	5.6	5.9	0.9	4.6	6.7	23.7
	Euro V	5.7	3.8	0.9	4.6	6.7	21.7
Truck-trailer combinations (34t - 40t, diesel engine, fleet 2010)	Euro 0	7.2	26.8	0.9	4.6	6.7	46.1
	Euro I	6.3	19.4	0.9	4.6	6.7	37.9
	Euro II	6.2	17.3	0.9	4.6	6.7	35.7
	Euro III	6.4	13.5	0.9	4.6	6.7	32.1
	Euro IV	6.2	6.8	0.9	4.6	6.7	25.3
	Euro V	6.3	4.5	0.9	4.6	6.7	23.0

Source: Calculations by IER as part of research project.

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 rate for each vehicle type. Here use was made of recommendations by INFRAS, based on data from the Federal Statistical Office and TREMOVE, and by Spielmann et al. (2007). This information is summarised in Table B15 below. It is important to note here that the occupancy figures for passenger trains differ considerably between the two sources cited. As can be seen from the table, the INFRAS data indicate an average occupancy of 112 persons per train.

By contrast, the ecoinvent data (identified by an asterisk) show an occupancy figure of 309 persons per train.

Table B15: Passenger numbers used per vehicle type

Passenger numbers		
Vehicle type	Persons / vehicle	Tonnes / vehicle
Cars	1.47	
Light commercial vehicles		0.8
Heavy goods vehicles		10.52
Motorcycle	1.11	
Bus fleet	17.10	
Local buses	16.3*	
Long-distance buses	14.6*	
Passenger train (general)	112.0 (309*)	
Passenger train (diesel)	31.8	
Passenger train (electric)	138.5	
Freight train (general)		497.0
Freight train (diesel)		223.6
Freight train (electric)		586.5

Source: Calculations by IER as part of research project.

Using these factors it is possible to convert all costs specified in vehicle kilometres into passenger kilometres (pkm) or tonne kilometres (tkm). For example, the environmental costs per kilometre when using a diesel car average 6 €-cent / vehicle kilometre. If the number of persons carried is 1.5 the environmental costs are 4 €-cent / passenger kilometre.

Table B16 shows the average environmental costs calculated in this way (for all routes) per passenger kilometre or per tonne kilometre.

Table B16: Environmental costs for various vehicle types in Germany in €-cent$_{2010}$ per passenger kilometre or tonne kilometre

Vehicle type		Total environmental costs	
Cars	Diesel	4.0	€-cent$_{2010}$ / passenger kilometre
	Petrol	3.1	€-cent$_{2010}$ / passenger kilometre
HGVs	Light commercial (diesel)	16.2	€-cent$_{2010}$ / tonne kilometre
	Light commercial (petrol)	12.1	€-cent$_{2010}$ / tonne kilometre
	Heavy goods (diesel)	2.4	€-cent$_{2010}$ / tonne kilometre
Bus	Diesel	2.2	€-cent$_{2010}$ / passenger kilometre
Motorcycles	Petrol (4-stroke)	3.2	€-cent$_{2010}$ / passenger kilometre
	Petrol (2-stroke)	3.3	€-cent$_{2010}$ / passenger kilometre
Passenger train	Diesel	8.1	€-cent$_{2010}$ / passenger kilometre
	Electric	0.8	€-cent$_{2010}$ / passenger kilometre
Freight train	Diesel	3.2	€-cent$_{2010}$ / tonne kilometre
	Electric	0.3	€-cent$_{2010}$ / tonne kilometre

Source: Calculations by IER as part of research project.

B 5 Environmental costs of heat and power generation

B 5.1 Environmental costs of power generation

To determine the environmental costs of power generation, it is necessary to have emission factors for the various power generation technologies. The Federal Environment Agency regularly publishes the emission factors in grams per kilowatt-hour of electricity (kWh_{el}) 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 emission factors and the above-mentioned environmental costs per tonne of pollutant emitted, it is possible to calculate environmental damage avoided and environmental costs for various power generation technologies.[24]

There are basically two methods of calculation. A differentiated analysis requires information and assumptions about the locations of the power generation facilities in Germany, on the basis of which it is possible, with the aid of models, to calculate the environmental damage costs[25] per kilowatt-hour of electricity. Another calculation method consists in taking average cost rates and using them as a basis for showing environmental costs. As a result, the calculations are easier to follow and in fact 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. Against this background, this method of calculation was used, for example, by Breitschopf (2012) to update the environmental damage costs in the regularly updated BMU publication "Renewable Energy Sources in Figures 2011". The results of these calculations are also shown here (cf. Table B17).

The emissions from the direct operating phase of the facilities are assessed using the average cost rates for Germany (cf. Table B4). However, indirect emissions arise not only in Germany, but also in other European countries. This is because the parts needed to construct a power generation facility are not necessarily all produced in Germany. Since it is not possible to determine the individual inputs and their countries of origin for each technology, the IER suggests using the EU cost rates (Table B5).

As a general rule, the Federal Environment Agency suggests the following guidelines for estimating the environmental costs of power generation:

- The average cost rates can be used for rough calculations of the environmental damage avoided and the environmental costs per unit of power or heat generated.
- Emissions from the direct operating phase should be valued using the German cost rates (Table B4).
- The indirect emissions should be valued using the EU cost rates (Table B5).
- For calculating site-specific environmental damage per technology or energy source, the Federal Environment Agency recommends using the differentiated cost rates in Table B6.

[24] See the detailed account in Breitschopf (2012), and BMU (2012) Erneuerbare Energien in Zahlen (Renewable Energy Sources in Figures).
[25] Cf. details in Müller/Preiss (2012).

Table B17: Environmental costs of power generation in Germany in €-cent2010 / kWhel

Electricity generation from	Air pollutants	Greenhouse gases	Total environmental costs
Lignite	2.07	8.68	10.75
Coal	1.55	7.38	8.94
Natural gas	1.02	3.90	4.91
Oil	2.41	5.65	8.06
Renewable energy sources			
Hydro power	0.14	0.04	0.18
Wind energy	0.17	0.09	0.26
Photovoltaic systems	0.62	0.56	1.18
Biomass*	2.78	1.07	3.84
* Average weighted by production shares for solid, liquid and gaseous biomass (households and industry), range from 0.3 to 7.2 ct/kWh_{el}			

Source: Breitschopf, B. (2012) and BMU (2012).

Power generation using lignite gives rise to the highest environmental costs, at 10.75 €-cent/kWh_{el}, followed by the fossil fuels coal and oil. The environmental costs of power generation from natural gas are considerably lower, and the most environmentally friendly solution is power generation from renewable energy sources. If renewable energy sources are weighted on the basis of their shares of power generation, the environmental costs of renewable energy sources average only around 1.8 €-cent pro kWh_{el} in terms of their shares of power generation in 2010. By contrast, the environmental costs of fossil fuels are higher, at around 7 to 9 €-cents per kWh_{el}. The environmental costs of Germany's electricity mix are 7.8 €-cent / kWh_{el}.

This shows that the promotion of renewable energy sources avoids substantial follow-on costs for health and the environment. Thus the environmental damage avoided by using renewable energy sources for power generation amounted to: [26]

- 2007: €5.6 billion
- 2008: €5.9 billion
- 2009: €5.7 billion

[26] Cf. Breitschopf et al. (2010), Breitschopf et al. (2011) and Breitschopf (2012).

- 2010: €5.8 billion
- 2011: €8.0 billion

It often makes sense to value the environmental costs of the average electricity mix, for example to quantify the scale of the environmental damage avoided as a result of energy savings. The average costs per kWh_{el} are calculated by weighting the share of power generation with the relevant cost rates.

For the year 2010 the results are as follows:

Electricity mix Germany (with nuclear power):	7.8 €-cent / kWh_{el}
Electricity mix Germany (without nuclear power):	7.0 €-cent / kWh_{el}
Electricity mix, renewable energy, Germany:	1.8 €-cent / kWh_{el}
Railway electricity mix:	7.0 €-cent / kWh_{el}

When estimating the environmental costs of nuclear power, there is the problem that the results of the studies show wide ranges of variation. The rule from the Methodological Convention[27] is used here to value nuclear power. This states that the emission factors for the technology with the highest environmental costs, in this case lignite, should be used to value the emissions due to nuclear energy.[28]

B 5.2 Environmental costs of heat generation

Table B18 shows the environmental costs of heat generation for the year 2010. Heating with coal and electricity causes the highest environmental costs by far. They are followed after a sizeable gap by district heating and heating with natural gas and oil. The environmental costs of renewable energy sources for heat generation are considerably lower still. This shows that the expansion of renewable energy on the heating market substantially reduces the resulting environmental costs.

[27] Cf. Methodological Convention 2.0, Chapter 2.5.4.
[28] For a more detailed treatment of this approach, see Methodological Convention 2.0, Chapter 2.5.4.

Table B18: Environmental costs of heat generation in Germany in €-cent$_{2010}$ / kWh$_{\text{final energy}}$

Heat generation using	Air pollutants	Greenhouse gases	Total environmental costs
Heating oil	0.80	2.52	3.32
Natural gas	0.26	2.02	2.28
Lignite (briquettes)	2.74	3.43	6.17
District heating with grid losses	0.88	2.60	3.48
Electric heating with grid losses*	1.14	5.15	6.29
Renewable energy sources			
Solar thermal	0.54	0.55	1.10
Shallow geothermal energy	0.39	1.75	2.13
Biomass**	1.63	0.25	1.88

* This is based on the average rate for power generation (including renewable energy sources and taking account of upstream chains for production of the relevant fuels. ** Average figure, weighted by production shares, for gaseous, liquid and solid biomass (household and industry), range from 0.56 – 3.2 €-cent/kWh.

Source: Breitschopf, B. (2012) and BMU (2012).

B Supplementary tables for transport emission factors

Table BA1: Emission factors for various vehicle types in Germany [in t / vehicle km]

		Exhaust								Abrasion		
		CH_4	CO_2	N_2O	NH_3	NMVOC	NO_x	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	PM_{coarse}
Cars (diesel)	Motorway	2.59E-10	1.50E-04	4.20E-09	1.00E-09	1.06E-08	7.64E-07	2.48E-08	8.09E-10	2.20E-08	2.20E-09	1.98E-08
	Rural	3.00E-10	1.25E-04	4.15E-09	1.00E-09	1.22E-08	4.87E-07	1.99E-08	6.79E-10	2.20E-08	2.20E-09	1.98E-08
	Urban	4.95E-10	1.67E-04	5.92E-09	1.00E-09	2.01E-08	6.17E-07	2.50E-08	9.05E-10	6.00E-08	6.00E-09	5.40E-08
Cars (petrol)	Motorway	2.76E-09	1.97E-04	9.92E-10	6.40E-08	3.41E-08	2.05E-07	6.98E-09	1.05E-09	2.20E-08	2.20E-09	1.98E-08
	Rural	2.36E-09	1.44E-04	1.40E-09	5.66E-08	3.09E-08	1.37E-07	2.65E-09	7.65E-10	2.20E-08	2.20E-09	1.98E-08
	Urban	3.76E-09	1.83E-04	3.07E-09	3.93E-08	5.05E-08	1.80E-07	1.78E-09	9.71E-10	6.00E-08	6.00E-09	5.40E-08
Light commercial (diesel)	Motorway	7.57E-10	2.47E-04	4.26E-09	1.00E-09	3.08E-08	1.81E-06	1.01E-07	1.34E-09	2.20E-08	2.20E-09	1.98E-08
	Rural	7.75E-10	1.94E-04	4.22E-09	1.00E-09	3.15E-08	1.13E-06	8.36E-08	1.05E-09	2.20E-08	2.20E-09	1.98E-08
	Urban	1.17E-09	2.10E-04	5.30E-09	1.00E-09	4.77E-08	1.02E-06	8.47E-08	1.14E-09	6.00E-08	6.00E-09	5.40E-08
Light commercial (petrol)	Motorway	1.41E-08	1.94E-04	5.08E-09	6.15E-08	2.48E-07	5.38E-07	1.66E-08	1.03E-09	2.20E-08	2.20E-09	1.98E-08
	Rural	8.17E-09	1.59E-04	6.18E-09	6.06E-08	1.69E-07	4.08E-07	8.02E-09	8.45E-10	2.20E-08	2.20E-09	1.98E-08
	Urban	1.23E-08	1.99E-04	9.60E-09	5.67E-08	2.83E-07	5.01E-07	5.47E-09	1.06E-09	6.00E-08	6.00E-09	5.40E-08
Heavy goods (diesel)	Motorway	2.24E-09	6.92E-04	3.47E-08	3.00E-09	9.11E-08	3.28E-06	5.08E-08	3.75E-09	2.00E-07	2.00E-08	1.80E-07
	Rural	2.48E-09	6.30E-04	2.92E-08	3.00E-09	1.01E-07	3.49E-06	6.44E-08	3.41E-09	2.00E-07	2.00E-08	1.80E-07
	Urban	5.29E-09	6.63E-04	2.16E-08	3.00E-09	2.15E-07	5.34E-06	1.04E-07	3.59E-09	6.00E-07	6.00E-08	5.40E-07

Motorcycles (petrol, 4-stroke)	Motorway	3.56E-08	1.37E-04	2.00E-09	2.00E-09	8.11E-07	6.59E-07	6.98E-09	7.27E-10	1.60E-08	1.60E-09	1.44E-08
	Rural	2.43E-08	9.59E-05	2.00E-09	2.00E-09	5.59E-07	2.75E-07	2.65E-09	5.10E-10	1.60E-08	1.60E-09	1.44E-08
	Urban	4.04E-08	1.02E-04	2.00E-09	2.00E-09	1.00E-06	1.36E-07	1.78E-09	5.44E-10	1.20E-08	1.20E-09	1.08E-08
Motorcycles (petrol, 2-stroke)	Motorway	4.13E-07	1.11E-04	2.00E-09	2.00E-09	4.55E-06	1.60E-07	2.48E-08	5.92E-10	1.60E-08	1.60E-09	1.44E-08
	Rural	3.28E-07	6.20E-05	1.19E-09	1.19E-09	3.06E-06	6.43E-08	1.99E-08	3.30E-10	1.60E-08	1.60E-09	1.44E-08
	Urban	3.17E-07	5.62E-05	1.04E-09	1.04E-09	2.85E-06	6.47E-08	2.50E-08	2.99E-10	1.20E-08	1.20E-09	1.08E-08
Buses	Motorway	5.80E-09	6.90E-04	5.87E-09	3.00E-09	2.36E-07	5.97E-06	1.27E-07	3.74E-09	2.00E-07	2.00E-08	1.80E-07
	Rural	6.43E-09	7.76E-04	6.65E-09	3.00E-09	2.61E-07	6.94E-06	1.52E-07	4.20E-09	2.00E-07	2.00E-08	1.80E-07
	Urban	1.37E-08	1.08E-03	8.44E-09	3.00E-09	5.57E-07	1.06E-05	2.77E-07	5.83E-09	6.00E-07	6.00E-08	5.40E-07

Passenger train (diesel)		3.64E-03			3.42E-06	6.45E-05	3.91E-06	4.40E-06
Passenger train (electric)	1.88E-05	5.71E-03			1.37E-07	3.00E-06	1.98E-07	3.07E-06
Freight train (diesel)		1.16E-02			1.09E-05	2.05E-04	1.24E-05	1.40E-05
Freight train (electric)	3.74E-05	1.14E-02			2.72E-07	5.97E-06	3.95E-07	6.11E-06

Source: Calculations by IER as part of research project.

Table BA2: Emission factors for life-cycle phases of various vehicle types in Germany [in t / vehicle km]

Vehicle type	Construction					Maintenance				
	CO_2	NMVOC	NO_X	$PM_{2.5}$	SO_2	CO_2	NMVOC	NO_X	$PM_{2.5}$	SO_2
Cars (diesel)	2.57E-05	4.99E-08	5.51E-08	1.18E-08	1.34E-07	4.83E-06	4.76E-09	9.81E-09	1.49E-09	1.78E-08
Cars (petrol)	2.57E-05	4.99E-08	5.51E-08	1.18E-08	1.34E-07	4.83E-06	4.76E-09	9.81E-09	1.49E-09	1.78E-08
Light commercial (diesel)	1.32E-05	1.78E-08	2.98E-08	7.92E-09	5.71E-08	1.01E-05	4.03E-09	1.83E-08	2.75E-09	3.48E-08
Light commercial (petrol)	1.32E-05	1.78E-08	2.98E-08	7.92E-09	5.71E-08	1.01E-05	4.03E-09	1.83E-08	2.75E-09	3.48E-08
HGV, 16t (diesel)	3.23E-05	3.64E-08	7.67E-08	1.51E-08	9.26E-08	1.88E-05	3.27E-08	3.22E-08	4.00E-09	5.56E-08
HGV, 28t (diesel)	4.61E-05	4.77E-08	1.09E-07	2.33E-08	1.36E-07	2.47E-05	4.24E-08	4.44E-08	6.34E-09	7.19E-08
HGV, 40t (diesel)	6.33E-05	6.29E-08	1.50E-07	3.32E-08	1.93E-07	3.53E-05	6.64E-08	6.63E-08	1.01E-08	1.04E-07
Motorcycles (petrol, 4-stroke)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Motorcycles (petrol, 2-stroke)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Buses	6.03E-05	5.23E-08	1.42E-07	3.98E-08	2.10E-07	3.23E-05	2.96E-08	4.34E-08	4.75E-09	6.13E-08
Passenger train	1.45E-03	9.91E-07	3.15E-06	7.32E-07	6.15E-06	9.45E-04	4.02E-06	1.78E-06	2.23E-07	2.21E-06
Freight train	1.45E-03	9.91E-07	3.15E-06	7.32E-07	6.15E-06	9.45E-04	4.02E-06	1.78E-06	2.23E-07	2.21E-06

Vehicle type	Disposal					Fuel supply				
	CO_2	NMVOC	NO_X	$PM_{2.5}$	SO_2	CO_2	NMVOC	NO_X	$PM_{2.5}$	SO_2
Cars (diesel)	2.50E-06	6.66E-10	2.18E-09	1.50E-10	1.66E-09	4.44E-05	2.18E-07	6.91E-08	1.65E-08	4.24E-07
Cars (petrol)	2.50E-06	6.66E-10	2.18E-09	1.50E-10	1.66E-09	7.79E-05	2.46E-07	1.54E-07	2.53E-08	6.91E-07
Light commercial (diesel)	1.90E-07	6.04E-11	2.83E-10	1.33E-11	8.42E-11	6.58E-05	3.23E-07	1.02E-07	2.45E-08	6.28E-07
Light commercial (petrol)	1.90E-07	6.04E-11	2.83E-10	1.33E-11	8.42E-11	7.95E-05	2.51E-07	1.57E-07	2.58E-08	7.06E-07
HGV, 16t (diesel)	1.24E-06	1.65E-10	9.76E-10	3.91E-11	1.53E-10	2.06E-04	1.01E-06	3.21E-07	7.68E-08	1.97E-06
HGV, 28t (diesel)	2.00E-06	3.07E-10	1.80E-09	7.13E-11	2.75E-10	2.06E-04	1.01E-06	3.21E-07	7.68E-08	1.97E-06
HGV, 40t (diesel)	2.00E-06	3.07E-10	1.80E-09	7.13E-11	2.75E-10	2.06E-04	1.01E-06	3.21E-07	7.68E-08	1.97E-06
Motorcycles (petrol, 4-stroke)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.35E-05	1.37E-07	8.58E-08	1.41E-08	3.86E-07
Motorcycles (petrol, 2-stroke)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.35E-05	1.37E-07	8.58E-08	1.41E-08	3.86E-07
Buses	2.51E-06	1.15E-10	7.73E-10	2.36E-11	1.16E-10	2.68E-04	1.32E-06	4.17E-07	9.98E-08	2.56E-06
Passenger train	3.94E-06	4.25E-09	2.00E-08	1.09E-09	2.83E-09					
Freight train	3.94E-06	4.25E-09	2.00E-08	1.09E-09	2.83E-09					

Source: Calculations by IER as part of research project.

Table BA3: Emission factors for various vehicle types in Germany by Euronorm categories [in t / vehicle km]

		Exhaust								Abrasion		
		CH_4	CO_2	N_2O	NH_3	NMVOC	NO_X	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	PM_{coarse}
Cars (petrol)	Euro 0 (low)	1.41E-08	1.60E-04	6.97E-09	2.00E-09	1.54E-07	7.98E-07	7.14E-09	8.57E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 0 (high)	4.33E-08	2.86E-04	1.13E-08	1.00E-07	1.24E-06	2.34E-06	1.18E-08	1.52E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 1	1.49E-08	2.12E-04	1.04E-08	9.99E-08	1.62E-07	7.98E-07	7.14E-09	1.12E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 2	5.02E-09	2.04E-04	5.02E-09	1.26E-07	5.48E-08	3.79E-07	1.09E-08	1.09E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 3	1.76E-09	1.99E-04	4.43E-10	4.06E-08	1.92E-08	6.59E-08	3.98E-09	1.06E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 4	7.50E-10	1.93E-04	4.80E-10	4.05E-08	8.17E-09	6.22E-08	2.05E-09	1.02E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 5	6.22E-10	1.79E-04	4.20E-10	4.03E-08	6.78E-09	5.56E-08	1.86E-09	9.54E-10	3.47E-08	3.47E-09	3.12E-08
Cars (diesel)	Euro 0	5.52E-09	1.84E-04	0.00E+00	1.00E-09	8.75E-08	6.74E-07	1.15E-07	9.17E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 1	1.34E-09	1.55E-04	3.73E-09	1.00E-09	5.47E-08	6.97E-07	1.19E-07	8.35E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 2	7.49E-10	1.43E-04	5.73E-09	1.00E-09	3.05E-08	7.42E-07	7.83E-08	7.62E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 3	4.53E-10	1.43E-04	4.67E-09	1.00E-09	1.84E-08	7.89E-07	3.73E-08	7.72E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 4	2.26E-10	1.42E-04	4.67E-09	1.00E-09	9.20E-09	5.31E-07	3.60E-08	7.63E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 5	2.33E-10	1.40E-04	4.67E-09	1.00E-09	9.49E-09	5.28E-07	1.47E-09	7.76E-10	3.47E-08	3.47E-09	3.12E-08
Motorcycles (2-stroke)	Euro 0	4.69E-07	9.82E-05	2.00E-09	2.00E-09	6.23E-06	8.37E-08	1.15E-07	5.13E-10	1.47E-08	1.47E-09	1.32E-08
	Euro 1	3.26E-07	9.09E-05	2.00E-09	2.00E-09	4.33E-06	5.70E-08	1.19E-07	4.77E-10	1.47E-08	1.47E-09	1.32E-08
	Euro 2	5.30E-07	7.72E-05	2.00E-09	2.00E-09	1.84E-06	7.13E-08	7.83E-08	4.06E-10	1.47E-08	1.47E-09	1.32E-08
	Euro 3	3.41E-07	6.43E-05	2.00E-09	2.00E-09	1.18E-06	7.32E-08	3.73E-08	3.38E-10	1.47E-08	1.47E-09	1.32E-08
Motorcycles (4-stroke)	Euro 0	3.97E-08	9.65E-05	2.00E-09	2.00E-09	1.14E-06	3.09E-07	1.18E-08	5.04E-10	1.47E-08	1.47E-09	1.32E-08
	Euro 1	2.19E-08	9.35E-05	2.00E-09	2.00E-09	6.28E-07	2.97E-07	7.14E-09	4.91E-10	1.47E-08	1.47E-09	1.32E-08

		Exhaust								Abrasion		
		CH_4	CO_2	N_2O	NH_3	NMVOC	NO_X	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	PM_{coarse}
	Euro 2	3.60E-08	9.17E-05	2.00E-09	2.00E-09	3.92E-07	2.71E-07	1.09E-08	4.83E-10	1.47E-08	1.47E-09	1.32E-08
	Euro 3	1.76E-08	9.45E-05	2.00E-09	2.00E-09	1.92E-07	1.95E-07	3.98E-09	4.97E-10	1.47E-08	1.47E-09	1.32E-08
Local buses	Euro 0	4.14E-08	1.09E-03	2.44E-09	3.00E-09	1.68E-06	1.61E-05	7.82E-07	5.92E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	1.46E-08	9.50E-04	2.44E-09	3.00E-09	5.93E-07	1.03E-05	3.93E-07	5.14E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	1.01E-08	9.28E-04	2.44E-09	3.00E-09	4.11E-07	1.07E-05	2.06E-07	5.02E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	9.16E-09	9.64E-04	1.22E-09	3.00E-09	3.72E-07	8.86E-06	1.83E-07	5.21E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	1.13E-09	9.33E-04	2.61E-09	3.00E-09	4.59E-08	6.03E-06	4.52E-08	5.05E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	1.15E-09	9.51E-04	6.76E-09	3.00E-09	4.68E-08	4.13E-06	4.62E-08	5.14E-09	3.33E-07	3.33E-08	3.00E-07
Long-distance buses	Euro 0	1.17E-08	7.92E-04	8.00E-09	3.00E-09	4.77E-07	1.11E-05	3.48E-07	4.29E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	1.17E-08	7.16E-04	8.00E-09	3.00E-09	4.77E-07	8.05E-06	2.80E-07	3.87E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	7.94E-09	7.19E-04	7.46E-09	3.00E-09	3.23E-07	8.63E-06	1.40E-07	3.88E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	7.62E-09	7.39E-04	4.46E-09	3.00E-09	3.10E-07	6.59E-06	1.42E-07	3.99E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	8.77E-10	7.26E-04	1.24E-08	3.00E-09	3.57E-08	4.31E-06	2.94E-08	3.92E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	9.01E-10	7.41E-04	3.62E-08	3.00E-09	3.66E-08	2.84E-06	3.01E-08	4.01E-09	3.33E-07	3.33E-08	3.00E-07
Light commercial (petrol)	Euro 0	5.13E-08	2.58E-04	7.11E-09	2.00E-09	1.47E-06	2.25E-06	1.63E-08	1.37E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 1	3.58E-08	2.35E-04	2.94E-08	1.02E-07	3.90E-07	1.42E-06	1.20E-08	1.25E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 2	1.23E-08	2.21E-04	1.81E-08	1.35E-07	1.35E-07	5.01E-07	1.84E-08	1.17E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 3	2.14E-09	2.02E-04	2.70E-09	3.73E-08	2.34E-08	8.76E-08	5.97E-09	1.07E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 4	1.21E-09	1.87E-04	4.43E-10	3.71E-08	1.32E-08	5.54E-08	4.20E-09	9.92E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 5	9.82E-10	1.34E-04	3.09E-10	3.69E-08	1.07E-08	3.88E-08	3.31E-09	7.11E-10	3.47E-08	3.47E-09	3.12E-08

		Exhaust								Abrasion		
		CH_4	CO_2	N_2O	NH_3	NMVOC	NO_X	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	PM_{coarse}
Light commercial (diesel)	Euro 0	5.49E-09	2.83E-04	0.00E+00	1.00E-09	2.23E-07	1.74E-06	3.21E-07	1.53E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 1	3.02E-09	2.38E-04	3.65E-09	1.00E-09	1.23E-07	1.50E-06	1.74E-07	1.29E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 2	1.37E-09	2.03E-04	5.65E-09	1.00E-09	5.55E-08	1.31E-06	9.73E-08	1.09E-09	3.47E-08	3.47E-09	3.12E-08
	Euro 3	2.09E-10	1.70E-04	4.88E-09	1.00E-09	8.50E-09	1.01E-06	4.73E-08	9.17E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 4	2.06E-10	1.73E-04	4.88E-09	1.00E-09	8.40E-09	8.57E-07	4.68E-08	9.33E-10	3.47E-08	3.47E-09	3.12E-08
	Euro 5	2.25E-10	1.17E-04	4.88E-09	1.00E-09	9.15E-09	6.96E-07	7.00E-10	6.35E-10	3.47E-08	3.47E-09	3.12E-08
HGV (< 7.5t)	Euro 0	1.56E-08	3.75E-04	3.41E-09	3.00E-09	6.35E-07	4.82E-06	2.50E-07	2.03E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	3.81E-09	3.24E-04	3.41E-09	3.00E-09	1.55E-07	3.49E-06	1.02E-07	1.75E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	2.54E-09	3.14E-04	3.38E-09	3.00E-09	1.03E-07	3.58E-06	5.49E-08	1.70E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	2.30E-09	3.31E-04	2.19E-09	3.00E-09	9.36E-08	2.53E-06	4.77E-08	1.79E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	3.22E-10	3.30E-04	6.03E-09	3.00E-09	1.31E-08	1.54E-06	9.96E-09	1.79E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	3.23E-10	3.30E-04	1.75E-08	3.00E-09	1.31E-08	9.00E-07	1.00E-08	1.79E-09	3.33E-07	3.33E-08	3.00E-07
HGV (7.5t - 12t)	Euro 0	1.24E-08	5.03E-04	3.41E-09	3.00E-09	5.03E-07	8.16E-06	2.40E-07	2.72E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	5.95E-09	4.47E-04	3.41E-09	3.00E-09	2.42E-07	4.87E-06	1.50E-07	2.42E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	3.89E-09	4.34E-04	3.38E-09	3.00E-09	1.58E-07	5.04E-06	8.16E-08	2.35E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	3.56E-09	4.56E-04	2.19E-09	3.00E-09	1.45E-07	3.60E-06	7.24E-08	2.47E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	4.82E-10	4.51E-04	6.03E-09	3.00E-09	1.96E-08	2.20E-06	1.51E-08	2.44E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	4.84E-10	4.52E-04	1.75E-08	3.00E-09	1.97E-08	1.34E-06	1.52E-08	2.45E-09	3.33E-07	3.33E-08	3.00E-07

		Exhaust								Abrasion		
		CH_4	CO_2	N_2O	NH_3	NMVOC	NO_X	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	PM_{coarse}
HGV (12t - 14t)	Euro 0	1.33E-08	5.30E-04	7.44E-09	3.00E-09	5.43E-07	8.62E-06	2.54E-07	2.87E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	6.33E-09	4.70E-04	7.44E-09	3.00E-09	2.57E-07	5.19E-06	1.61E-07	2.54E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	4.18E-09	4.57E-04	6.63E-09	3.00E-09	1.70E-07	5.39E-06	8.78E-08	2.47E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	3.82E-09	4.78E-04	4.19E-09	3.00E-09	1.56E-07	3.91E-06	7.90E-08	2.59E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	4.91E-10	4.69E-04	1.18E-08	3.00E-09	2.00E-08	2.34E-06	1.59E-08	2.54E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	4.93E-10	4.70E-04	3.45E-08	3.00E-09	2.00E-08	1.44E-06	1.60E-08	2.54E-09	3.33E-07	3.33E-08	3.00E-07
HGV (14t - 20t)	Euro 0	1.96E-08	6.43E-04	7.44E-09	3.00E-09	7.98E-07	1.03E-05	3.22E-07	3.48E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	8.73E-09	5.45E-04	7.44E-09	3.00E-09	3.55E-07	6.15E-06	2.06E-07	2.95E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	5.88E-09	5.30E-04	6.63E-09	3.00E-09	2.39E-07	6.47E-06	1.10E-07	2.87E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	5.52E-09	5.56E-04	4.19E-09	3.00E-09	2.25E-07	4.69E-06	1.10E-07	3.01E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	6.00E-10	5.36E-04	1.18E-08	3.00E-09	2.44E-08	2.92E-06	1.96E-08	2.90E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	6.06E-10	5.37E-04	3.45E-08	3.00E-09	2.47E-08	1.87E-06	1.97E-08	2.91E-09	3.33E-07	3.33E-08	3.00E-07
HGV (20t - 26t)	Euro 0	1.04E-08	7.53E-04	7.44E-09	3.00E-09	4.25E-07	1.07E-05	3.29E-07	4.08E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	1.02E-08	7.05E-04	7.44E-09	3.00E-09	4.13E-07	7.49E-06	2.53E-07	3.55E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	6.79E-09	6.42E-04	6.63E-09	3.00E-09	2.76E-07	7.89E-06	1.35E-07	3.47E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	6.28E-09	6.67E-04	4.19E-09	3.00E-09	2.55E-07	5.84E-06	1.30E-07	3.61E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	6.85E-10	6.42E-04	1.18E-08	3.00E-09	2.79E-08	3.51E-06	2.34E-08	3.48E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	6.90E-10	6.44E-04	3.45E-08	3.00E-09	2.81E-08	2.21E-06	2.36E-08	3.48E-09	3.33E-07	3.33E-08	3.00E-07

		Exhaust								Abrasion		
		CH_4	CO_2	N_2O	NH_3	NMVOC	NO_X	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	PM_{coarse}
HGV (26t - 28t)	Euro 0	1.08E-08	7.96E-04	7.44E-09	3.00E-09	4.41E-07	1.13E-05	3.46E-07	4.31E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	1.05E-08	6.93E-04	7.44E-09	3.00E-09	4.28E-07	7.82E-06	2.67E-07	3.75E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	7.12E-09	6.84E-04	6.63E-09	3.00E-09	2.90E-07	8.03E-06	1.45E-07	3.70E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	6.56E-09	7.06E-04	4.19E-09	3.00E-09	2.67E-07	6.00E-06	1.38E-07	3.82E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	7.53E-10	6.83E-04	1.18E-08	3.00E-09	3.06E-08	3.61E-06	2.53E-08	3.70E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	7.56E-10	6.85E-04	3.45E-08	3.00E-09	3.07E-08	2.26E-06	2.55E-08	3.71E-09	3.33E-07	3.33E-08	3.00E-07
HGV (28t - 32t)	Euro 0	1.16E-08	9.06E-04	1.09E-08	3.00E-09	4.70E-07	1.30E-05	3.83E-07	4.90E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	1.13E-08	7.96E-04	1.09E-08	3.00E-09	4.60E-07	9.05E-06	2.99E-07	4.31E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	7.65E-09	7.89E-04	1.09E-08	3.00E-09	3.11E-07	9.28E-06	1.63E-07	4.27E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	7.06E-09	8.14E-04	6.38E-09	3.00E-09	2.87E-07	6.83E-06	1.51E-07	4.41E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	8.79E-10	7.97E-04	1.80E-08	3.00E-09	3.57E-08	4.08E-06	2.85E-08	4.31E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	8.85E-10	8.00E-04	5.30E-08	3.00E-09	3.60E-08	2.52E-06	2.87E-08	4.33E-09	3.33E-07	3.33E-08	3.00E-07
HGV (> 32t)	Euro 0	1.15E-08	8.97E-04	1.09E-08	3.00E-09	4.66E-07	1.29E-05	3.88E-07	4.85E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	1.15E-08	7.85E-04	1.09E-08	3.00E-09	4.68E-07	9.00E-06	3.03E-07	4.25E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	7.58E-09	7.72E-04	1.09E-08	3.00E-09	3.08E-07	9.41E-06	1.61E-07	4.18E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	6.97E-09	7.97E-04	6.38E-09	3.00E-09	2.83E-07	7.03E-06	1.50E-07	4.31E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	8.11E-10	7.75E-04	1.80E-08	3.00E-09	3.30E-08	4.10E-06	2.75E-08	4.19E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	8.18E-10	7.77E-04	5.30E-08	3.00E-09	3.33E-08	2.55E-06	2.77E-08	4.21E-09	3.33E-07	3.33E-08	3.00E-07

		Exhaust								Abrasion		
		CH_4	CO_2	N_2O	NH_3	NMVOC	NO_X	$PM_{2.5}$	SO_2	PM_{10}	$PM_{2.5}$	PM_{coarse}
Truck-trailer (20t - 28t)	Euro 0	1.01E-08	7.45E-04	7.44E-09	3.00E-09	4.10E-07	1.06E-05	3.22E-07	4.03E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	9.82E-09	6.62E-04	7.44E-09	3.00E-09	3.99E-07	7.44E-06	2.52E-07	3.58E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	6.64E-09	6.44E-04	6.63E-09	3.00E-09	2.70E-07	7.63E-06	1.34E-07	3.48E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	6.09E-09	6.69E-04	4.19E-09	3.00E-09	2.48E-07	5.63E-06	1.28E-07	3.62E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	7.11E-10	6.53E-04	1.18E-08	3.00E-09	2.89E-08	3.44E-06	2.33E-08	3.53E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	7.14E-10	6.55E-04	3.45E-08	3.00E-09	2.90E-08	2.15E-06	2.34E-08	3.54E-09	3.33E-07	3.33E-08	3.00E-07
Truck-trailer (28t - 34t)	Euro 0	9.99E-09	7.80E-04	1.09E-08	3.00E-09	4.06E-07	1.12E-05	3.34E-07	4.22E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	9.87E-09	6.95E-04	1.09E-08	3.00E-09	4.01E-07	7.81E-06	2.63E-07	3.76E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	6.66E-09	6.79E-04	1.09E-08	3.00E-09	2.71E-07	7.98E-06	1.40E-07	3.67E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	6.10E-09	7.04E-04	6.38E-09	3.00E-09	2.48E-07	5.91E-06	1.32E-07	3.81E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	7.24E-10	6.88E-04	1.80E-08	3.00E-09	2.94E-08	3.54E-06	2.39E-08	3.72E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	7.29E-10	6.90E-04	5.30E-08	3.00E-09	2.97E-08	2.19E-06	2.41E-08	3.73E-09	3.33E-07	3.33E-08	3.00E-07
Truck-trailer (34t - 40t)	Euro 0	1.17E-08	8.87E-04	1.19E-08	3.00E-09	4.77E-07	1.27E-05	3.86E-07	4.80E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 1	1.15E-08	7.78E-04	1.19E-08	3.00E-09	4.69E-07	8.85E-06	3.05E-07	4.21E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 2	7.63E-09	7.68E-04	1.10E-08	3.00E-09	3.10E-07	9.21E-06	1.62E-07	4.16E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 3	6.97E-09	7.90E-04	7.38E-09	3.00E-09	2.83E-07	6.92E-06	1.50E-07	4.28E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 4	8.08E-10	7.70E-04	1.99E-08	3.00E-09	3.29E-08	4.09E-06	2.69E-08	4.17E-09	3.33E-07	3.33E-08	3.00E-07
	Euro 5	8.11E-10	7.72E-04	5.73E-08	3.00E-09	3.30E-08	2.56E-06	2.70E-08	4.18E-09	3.33E-07	3.33E-08	3.00E-07

Source: Calculations by IER as part of research project.

Bibliography

Anthoff, D. (2007): Report on marginal external damage costs inventory of greenhouse gas emissions, NEEDS Delivery No. 4 – RS 1b, 2007.

Blasing, T. J. (2012): Recent Greenhouse Gas Concentrations, (Updated February 2012); DOI: 10.3334/CDIAC/atg.032; http://cdiac.ornl.gov/pns/current_ghg.html.

BMU (2012): Erneuerbare Energien in Zahlen – Nationale und internationale Entwicklung, http://www.erneuerbare-energien.de/files/pdfs/allgemein/application/pdf/broschuere_ee_zahlen_bf.pdf .

Breitschopf, B. (2012): Ermittlung vermiedener Umweltschäden – Hintergrundpapier zur Methodik im Rahmen des Projektes „Wirkungen des Ausbaus erneuerbarer Energien“, im Auftrag des BMU, http://www.erneuerbare-energien.de/files/pdfs/allgemein/application/pdf/hg_umweltschaeden_bf.pdf .

Breitschopf, B. et al. (2011), Einzel- und gesamtwirtschaftliche Analyse von Kosten- und Nutzenwirkungen des Ausbaus Erneuerbarer Energien im deutschen Strom- und Wärmemarkt – Update der qualifizierten Kosten- und Nutzenwirkungen für 2010, Untersuchung im Auftrag des BMU.

Breitschopf, B. et al. (2010), Einzel- und gesamtwirtschaftliche Analyse von Kosten- und Nutzenwirkungen des Ausbaus Erneuerbarer Energien im deutschen Strom- und Wärmemarkt – Update der qualifizierten Kosten- und Nutzenwirkungen für 2009, Untersuchung im Auftrag des BMU.

CE Delft (2008), Handbook on estimation of external costs in the transport sector - IMPACT D1, Version 1.1 February, 2008.

De Ceuster, G., van Herbruggen, B., Ivanova, O., Carlier, K., Martino, A. and Fiorello, D. (2007): TREMOVE. Service contract for the further development and application of the transport and environmental TREMOVE model, Lot 1 (Improvement of the data set and model structure), Service Contract 070501/2005/420798/MAR/C1, Final Report, European Commission, Directorate General Environment, Brussels.

ExternE (2005): Externalities of Energy – Methodology 2005 update, edited by Peter Bickel and Rainer Friedrich, Institut für Energiewirtschaft und Rationelle Energieanwendung; DG Research; EUR 21951.

Friedrich, R., Kuhn, A., Bessagnet, B., Blesl, M., Bruchof, D., Cowie, H., et al. (2011): D 5.3.1/2 Methods and results of the HEIMTSA/INTARESE Common Case Study, http://www.integrated-assessment.eu/sites/default/files/CCS_FINAL_REPORT_final.pdf.

HBEFA (2010): Handbuch Emissionsfaktoren des Straßenverkehrs (HBEFA), Version 3.1, Umweltbundesamt Berlin, Bundesamt für Umwelt, Wald und Landschaft Bern, Bern, INFRAS AG.

IFEU (2010): Daten- und Rechenmodell: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland"(TREMOD, Version 5.1), Heidelberg.

INFRAS/IWW (2004): External costs of transport, Update Study, Zürich, Karlsruhe.

IPCC (International Panel on Climate Change) (2007a): Climate Change 2007: The Physical Science Basis, Summary for Policy Makers. Contribution of Working Group I to the Fourth Assessment Report of the IPCC.

Kugler, U., Jörß, W. Theloke, J. (2010): Verkehrsemissionsmodellierung - Modellvergleich und Alternative Szenarien. UFOPLAN FKZ 206 43 200/01.

Kugler, U. (2012): Straßenverkehrsemissionen in Europa – Emissionsberechnung und Bewertung von Minderungsmaßnahmen, Dissertation, Institut für Energiewirtschaft und Rationelle Energieanwendung der Universität Stuttgart, http://elib.uni-stuttgart.de/opus/volltexte/2012/7039/pdf/FB107_OPUS.pdf .

Kuik, O., Brander, L. and Tol, R. S. J. (2009): Marginal abatement costs of greenhouse gas emissions: A meta-analysis, Energy Policy 37, p. 1395–1403.

Maibach, M. et al. (2007): Praktische Anwendung der Methodenkonvention: Möglichkeiten der Berücksichtigung externer Umweltkosten bei Wirtschaftlichkeitsrechnungen von öffentlichen Investitionen. Final report March 2007. Studie im Auftrag des Umweltbundesamtes.

Müller, W./ Preiss, P. (2012), Kostensätze für Luftschadstoffe, Verkehr, Strom- und Wärmeerzeugung, IER, Version: 5 June 2012.

Müller, W., Preiss, P., Klotz, V. and Friedrich, R. (2010): External cost values for EE SUT framework – Final report providing external cost values to be applied in an EE SUT framework, Deliverable DIII,1,b-2, EXIOPOL (A new environmental accounting framework using externality data and input-output tools for policy analysis), https://feem-projectnet.serversicuro.it/exiopol/index.php.

Ohlau, K., Preiss, P. and Friedrich, R. (2012): Lärm, Sachstandspapier im Rahmen des Vorhabens „Schätzung Externer Umweltkosten und Vorschläge zur Kosteninternalisierung in ausgewählten Politikfeldern“, Umweltbundesamt, Forschungsprojekte FKZ 3708 14 101, Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart.

Preiss, P., Friedrich, R. and Klotz V. (2008): Report on the procedure and data to generate averaged/aggregated data, Deliverable No. 1.1 - RS 3a, NEEDS (New Energy Externalities Developments for Sustainability), http://www.needs-project.org.

Preiss, P., Müller, W., Torras, S., Kuhn, A. and Friedrich, R. (2012): Klassische Luftschadstoffe, Sachstandspapier im Rahmen des Vorhabens „Schätzung Externer Umweltkosten und

Vorschläge zur Kosteninternalisierung in ausgewählten Politikfeldern“, Umweltbundesamt, Forschungsprojekt FKZ 3708 14 101, Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart.

Spielmann, M., Bauer, C., Dones, R. and Tuchschmid, M. (2007): Transport Services, Data v2.0, Ecoinvent report No. 14, Villingen and Uster, December 2007.

Sutter, D. (2011): Kostensatz Natur und Landschaft. Personal communication in connection with the Methodological Convention for Estimating Environmental Externalities. UBA, research projects FKZ 3708 14 101, INFRAS, E-mail of 24 February 2011.

Torras Ortiz, S. (2010), A hybrid dispersion modelling approach for quantifying and assessing air quality in Germany with focus on urban background and kerbside concentrations, Dissertation, Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart.

UBA (Umweltbundesamt) (2007): Ökonomische Bewertung von Umweltschäden – Methodenkonvention zur Schätzung externer Umweltkosten, Umweltbundesamt, April 2007.

Watkiss, P. et al. (2005), The Impacts and Costs of Climate Change, final Report prepared as task 1 of the project ‘Modelling support for Future Actions: Benefits and Cost of Climate Change Policies and Measures’, Brussels: Commissioned by European Commission DG Environment, 2005, http://europa.eu.int/comm/environment/climat/pdf/final_report2.pdf.

Wille, V., Preiss, P. and Friedrich, R. (2012): Sachstandspapier zu Treibhausgase & Klimawandel, Sachstandspapier im Rahmen des Vorhabens “Schätzung Externer Umweltkosten und Vorschläge zur Kosteninternalisierung in ausgewählten Politikfeldern”, Umweltbundesamt, Forschungsprojekte FKZ 3708 14 101, Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart.