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Version 2019

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Content

Glossary

Term	Explanation
AG	Age Group
AIS	Abbreviated Injury Scale
CBA	Cost Benefits Analysis
CEMT class	Size class for inland waterway vessels and barges
CH_4	Methane
CRF	Concentration Response Function
CO_2	Carbon-dioxide
DALY	Disability-Adjusted Life Year
Db (A)	Decibel (A-weighted)
EBD	Environmental burden of disease
EDP	Ecosystem Damage Potential
EEA	European Environmental Agency
EMEP	European Monitoring and Evaluation Program for the long-range transmission of air pollution
ERA	European Union Agency for Railways
ERF	Exposure Response Function
ETS	Emission Trading Scheme
DWL	Dead Weight Loss
GDP	Gross Domestic Product
GHG	Greenhouse gas
Gt	Gross tonnage
GWP	Global Warming Potential
HGV	Heavy Goods Vehicle
HSL	High Speed Line
IAM	Integrated Assessment Model (for climate change)
IMPACT	Internalisation Measures and Policies for All Modes of Transport (study that delivered the first EU wide Handbook on external cost)
IWT	Inland Waterway Transport
kton	Kiloton
LCV	Light Commercial Vehicle
Lden	Level-day-evening-night (weighted noise measure)
LRS	Lower Respiratory Symptoms
LTO	Landing-and -take-off
MC	Motorcycle
MRAD	Minor Restricted Activity Days
N_2O	Nitrous-oxide
NH_3	Ammonia
NMVOC	Non-methane Volatile Organic Compounds
NO_x	Nitrogen-oxides
NSDI	Noise Sensitivity Depreciation Indexes
NUTS-3	Category in the classification of territorial units for statistics indicating small regions
PAH	Polycyclic Aromatic Hydrocarbon
Pax	Passengers
PCE	Passenger Car Equivalent
PDF	Physical Damage Factor
Pkm	Passenger-kilometre
PM	Particulate Matter

Term	Explanation
$PM_{2.5}$	Particulate Matter smaller than 2.5 micro-metre
PM_{10}	Particulate Matter smaller than 10 micro-metre
ppm	Parts Per Million
ppb	Parts per Billion
PPP	Purchasing Power Parity
QALY	Quality-Adjusted Life Years
RAD	Restricted Activity Days
RG	Risk Group
RoPax	Roll-on-roll-of Passenger ship or ferry
RP	Revealed Preference
RR	Relative Risk or Relative Risk factor
SIA	Secondary Inorganic Aerosols
SO_2	Sulphur-dioxide
SOMO 35	Sum of ozone means over 35 ppb
SP	Stated Preference
t	Metric tonnes
TEU	Twenty Foot Equivalent Unit (volume of a 20 foot container)
Tkm	Tonne-kilometre
Vkm	Vehicle-kilometre
VSL	Value of Statistical Life
VOC	Volatile Organic Compound
VOLY	Value Of Life Year lost
WHO	World Health Organisation
WLD	Work Loss Days
WTT	Well To Tank
WTP	Willingness To Pay
YLD	Years Lost due to Disability
YOLL	Years of Life Lost

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- Christopher Nash, research professor on transport economics from the University of Leeds
- Stale Navrud, Professor of School of Economics and Business at the Norwegian University of Life Sciences
- Stefaan Proost, Prof. at Faculty of Economics and Business, University of Leuven/Belgium
- Cristoph Lieb Senior Consultant in transport economics, ECOPLAN
- Alexandra Quandt, Swiss Federal Office of Statistics
- Martin Adler, specialist in transport and urban economics
- Panayotis Christidis, Joint Research Centre JRC C.6

1 Introduction

1.1 Background of the Handbook

Overview of the study and other deliverables

This updated Handbook on external costs of transport has been developed in the study 'Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities' commissioned by the European Commission DG MOVE, by a consortium led by CE Delft. The objective of this study is to assess the extent to which the 'user pays' and the 'polluter pays' principles are implemented in EU Member States and in other developed countries. This will allow DG MOVE to take stock of the progress of Member States towards the goal of full internalisation of external (and infrastructure) costs of transport and to identify options for further internalisation.

The full list of deliverables of this study are:

- Handbook on external costs – version 2019 (current report).
  - This report provides an overview of the methodologies and input values that can be used to provide state-of-the-art estimates for all main external costs of transport. Furthermore, the report and corresponding excel file present the total, average and marginal external costs for all relevant countries.
- Overview of transport infrastructure expenditures and costs.
  - This report provides an overview of the infrastructure costs of all transport modes in all relevant countries.
- Transport taxes and charges in Europe - An overview study of economic internalisation measures applied in Europe.
  - This study provides an overview of the structure and level of transport taxes and charges applied for the various transport modes in the EU28 Member States (and the other relevant countries). Furthermore, this study presents the total revenues from transport taxes and charges for the various transport modes and countries.
- The state of play of internalisation in the European transport sector.
  - This report shows the extent to which external and infrastructure costs are internalised by current taxes and charges for all countries and transport modes.It also investigates recommended options for further internalisation.
- Summary report.
  - Providing an overview of the main findings of the other four deliverables.

In 2008 the European Commission commissioned the first Handbook on External Costs of Transport, as part of the IMPACT study (Infras, CE Delft, ISI & University of Gdansk, 2008). This Handbook presented the best practice on the methodology to estimate different categories of external costs of transport. Additionally, it provided an overview of state of the art input values (e.g. the value of time or the value of a statistical life) that can be used to produce estimations of external costs by users of the Handbook themselves. Finally, the Handbook presented external cost figures (mostly presented in €/vehicle kilometre), which can be used directly by the users.

The 2008 Handbook focus was on marginal external costs of transport as a basis for the definition of internalisation policies (in line with the marginal social cost pricing principle). It covered all main external cost categories, including air pollution, climate change, noise, accidents and congestion. The Handbook was based on the existing (up to 2007) scientific and expert work, mainly carried out at the EU level and within European countries. It was reviewed by a panel of more than thirty experts, including experts who were designated by Member States.

In 2014 the Handbook was updated with new developments in research and policy (Ricardo-AEA, TRT, DIW Econ & CAU, 2014). Furthermore, the scope was broadened: next to the external costs of transport, infrastructure wear and tear costs for road and rail transport were covered as well. In line with the 2008 Handbook, the focus of the 2014 Handbook was on marginal external costs of transport. Next to the Handbook, an accompanying Excel file was produced, containing country specific estimates of the main external costs of road and rail transport.

This Handbook is an update of the 2008 and 2014 version, taking into account any new evidence that has become available on the methods and input values (e.g. emission factors) for estimating external costs of transport in research and policy since 2014. This version of the Handbook does not only consider marginal external costs, as was the main focus of the previous Handbooks, but also total and average external costs of transport in all EU-countries, Switzerland and Norway. Furthermore, external cost figures for some non-European countries were produced to compare them with the European figures.

1.2 Objective

The objective of this Handbook is to provide information on how to generate state-of-the-art estimates for all main external costs of transport. This information is provided at three levels:
- *Methodological level*: what are the state of the art methodologies to estimate figures for the various external costs of transport?
- *Input values*: which input values (particularly at monetary terms, e.g. the value of time) are recommended to use to estimate external costs of transport?
- *Output values*: which default external cost values for different transport modes (and if meaningful, for different traffic situations) can be recommended?

In this Handbook, state of the art methodologies, input values and output values for total, average and marginal external costs of transport are provided, both at the EU28 level as at the level of individual countries. This is done for all transport modes and all (main) external cost categories.

1.3 Scope

1.3.1 External cost categories

This Handbook covers all main externalities of transport:
- accidents;
- air pollution;
- climate change;
- noise;
- congestion;
- well-to-tank emissions;
- habitat damage;
- other external cost categories (e.g. soil and water pollution).

Transport infrastructure costs are not considered in this Handbook, as it is addressed in a parallel study carried out within the broader project on internalisation of external and infrastructure costs of transport (see the text box in Section 1).

1.3.2 Transport modes

This Handbook considers road transport, rail transport, inland waterway transport (IWT), maritime transport and aviation. Total and average cost figures are produced for the vehicle categories shown in Table 1. Furthermore, cost-specific differentiations of the external cost estimates are produced when relevant (e.g. average/marginal air pollution costs of passenger cars are differentiated to Euro class).

Table 1 – Transport modes and vehicle types covered

Road transport	Rail transport	IWT	Maritime transport	Aviation*
– Passenger car – Motorcycle – Bus – Coach – LCV – Heavy Goods Vehicle (HGV)	– High speed passenger train (HSL) – Passenger train electric – Passenger train diesel – Freight train electric – Freight train diesel	– Inland vessel	– Freight vessel – Ferry	– Passenger aircraft

* Freight aviation is not considered in this Handbook, as the data to provide reliable figures on all external cost categories is missing.

1.3.3 Geographical coverage

For road transport, rail transport and IWT, input and output values are produced for all EU28 countries, Norway, Switzerland, Canada, US, and Japan. For Canada and the United States external costs are considered at the province/state level, i.e. California, Missouri (both US), British Columbia and Alberta (both Canada)[1].

[1] Both for the US and Canada, a front runner and laggard state/province with respect to the internalisation of external costs have been selected. For the US, California has been selected as a front runner state, among other things because fuel and vehicle taxes are among the highest in the US and broad enabling legislation for toll roads has been implemented. Furthermore, California is known for its progressive policies in the transport sector (e.g. regarding electric vehicles). Missouri, on the other hand, shows relatively low fuel and vehicle taxes as well as limited road charging legislation, suggesting a low level of internalisation. For that reason, Missouri is selected a laggard state. According to Corporate Knights (2015), British Columbia can be regarded as the Canadian province with the highest environmental performance for the transport sector, while Alberta is ranked lowest. Therefore, British Columbia (front-runner) and Alberta (laggard) has been selected as Canadian provinces in this study.

For maritime shipping and aviation, external cost figures (output values) are not provided at the national/state level, but at the level of individual (air)ports[2]. The selection of (air)ports considered in this study is given in Table 2. This selection is made based on the following criteria:

- Airports:
  1. Of all considered countries the largest airport is analysed.
  2. In Canada and the US, the two largest airports are included.
  3. In Europe, the five largest airports, which are not already included in the criteria above, are also considered.
  4. Only international airports (with international flights) are covered in the analysis.
- Maritime ports:
  1. All 24 maritime ports considered in the study *'Assessment of potential of maritime and inland ports and inland waterways and of related policy measures, including industrial policy measures'* (EY, et al., ongoing) are covered. The maritime ports considered in this study provide a good representation of main EU ports with growth potential up to 2030.
  2. As not all countries were covered by the ports selected in Step 1, an additional set of ten ports was included to cover the main maritime ports for all European countries considered in this study.
  3. In order to provide a good representation of the main ferry/RoPax ports as well, an additional German port was added to the list.
  4. A sample of five overseas ports in the US, Canada and Japan have been selected.

Table 2 - Airports and maritime ports covered

Country	Airport(s)	Maritime port(s)	
		Freight ports	Ferry ports
Austria	Wien - Schwechat		
Belgium	Brussels	Antwerp	Antwerp
Bulgaria	Sofia	Varna	
Croatia	Zagreb Pleso	Rijeka Split	Rijeka Split
Cyprus	Larnaka	Lemessos	
Czech Republic	Prague Ruzyne		
Denmark	Copenhagen - Kastrup	Arhus Helsingør (Elsinore)	Arhus Helsingør (Elsinore)
Estonia	Lennart Meri Tallinn	Tallinn	Tallinn
Finland	Helsinki - Vantaa	Helsinki	Helsinki
France	Paris - Charles de Gaulle Paris - Orly	Calais Le Havre Marseille	Calais Marseille
Germany	Frankfurt Munich	Hamburg Bremerhaven	Travemünde
Greece	Athens Eleftheriios Venizelos	Piraeus	Piraeus
Hungary	Budapest Liszt Ferenc		
Ireland	Dublin	Dublin	Dublin
Italy	Roma - Fiumicino	Genova	Genova

[2] This is done to be consistent with the other studies carried out within the broader study on the internalisation of external and infrastructure costs (see text box in Section 1). Both in the study on infrastructure costs and the study on taxes and charges the (air)port level is a more appropriate scope than the country level, as data on infrastructure costs and taxes/charges are mainly available at the (air)port level.

Country	Airport(s)	Maritime port(s)	
		Freight ports	Ferry ports
		Trieste Venice	Trieste Venice
Latvia	Riga	Riga	Riga
Lithuania	Vilnius	Klaipeida	Klaipeida
Luxembourg	Luxembourg		
Malta	Luga	Marsaxxlokk	
Netherlands	Amsterdam - Schiphol	Rotterdam	Rotterdam
Poland	Warsaw Chopina	Gdansk	Gdansk
Portugal	Lisboa	Sines	
Romania	Bucharest Henri Coandă	Constantza	
Slovakia	Bratislava M.R. Stefanik		
Slovenia	Ljubljana Brink	Koper	
Spain	Barcelona - El Prat Adolfo Suarez Madrid - Barajas Palma de Mallorca	Algeciras Barcelona Bilbao Valencia	Algeciras Barcelona Bilbao Valencia
Sweden	Stockholm - Arlanda	Goteborg	Goteborg
United Kingdom	London - Heathrow London - Gatwick	Felixstowe	
Norway	Oslo - Gardermoen	Oslo	Oslo
Switzerland	Zurich		
Canada	Toronto/Lester B Pearson Intl. Ont. Vancouver International B.C.	Vancouver Montreal	
United States	Atlanta Hartsfield - Jackson International Los Angeles International	Los Angeles Savannah	
Japan	Haneda Airport Tokyo	Tokyo	

1.3.4 Transport performance data

To estimate the various external cost figures (output values), several types of transport performance data (e.g. vkms, tkms, pkms) have been used. For the purpose of this Handbook a consistent set of transport performance data has been composed, mainly based on EU aggregated sources (like Eurostat and COPERT). For maritime transport and aviation, (air)port specific transport performance data (e.g. number of calls, LTOs) are collected from port authorities and annual reports of the considered (air)ports directly.

Road transport performance data is taken from Eurostat, following the nationality principle, i.e. transport activity is allocated to countries where the vehicle is registered. In an alternative approach, the territorial principle, transport activity is allocated to the countries where the activity actually takes place. For example, kilometres driven by Polish vehicles in Germany are accounted to Poland if the nationality principle applies, and to Germany if the territorial principle applies. The territorial principle would have been more consistent with the scope of the external costs. However, as a detailed EU-wide data set on road transport performance based on the territorial principle is not available, the official Eurostat data set based on the nationality principle has been used for this study. This choice (i.e. to apply road transport performance data based on the nationality principle) affects the results, in particular the allocation of the noise and accident costs from road transport to different vehicle categories.

1.3.5 Base year

All input and output values in this Handbook are presented for 2016. If some data was not available for 2016, data for the most recent year (preferably 2015) was used.

1.3.6 Price level

All financial figures are expressed in Euro price levels of 2016. Data from sources where price levels from other years were used, are translated to price level 2016 by using relevant price index figures (from Eurostat). Furthermore, all financial figures are adjusted for differences in purchase power between countries (by using Purchasing Power Standards, PPS), in order to allow for direct comparisons between counties. This implies that all financial figures are shown for the EU28 average price level.

1.4 User guide: how to use this Handbook

This Handbook includes guidelines for estimating external costs of transport at three levels which differ with respect to the level of accuracy of the values produced:

- *Methodological level*: for each external cost category recommendations on the best practice methodologies to estimate total/average and marginal external cost values are provided. Using these methodologies to produce own differentiated cost figures based on case specific input values results in the most accurate outcomes. However, this level requires the availability of case-specific estimates of key input parameters and evaluation models.
- *Input values*: for each external cost category typical European and Member State values for key input parameters are provided. Examples of input values are the Value of Time (in € per hour), the Value of a Life Year lost (€ per life year lost), etc. These input values can be used to produce own output values in cases some case-specific data is available.
- *Output values*: for ready estimations with limited case-specific data, total/average and marginal external cost figures are provided for all countries and transport modes. Where relevant, differentiations to relevant vehicle characteristics (e.g. fuel type, size class, etc.) and traffic situation (type of road, day/night, thin/dense traffic, etc.) are provided.

The guidelines at these three levels (methodologies, input values and output values) are given for each external cost category in Chapters 3 to 9 in the main text of this Handbook. These chapters all follow the same structure:

- Definition and scope of the externality considered is briefly discussed.
- Recommended methodologies, input values and output values for total/average cost figures are presented. Input and output values are presented for the EU28.
  National values are presented in the Excel Annex accompanying this Handbook (see Annex K for more details).
- Recommended methodologies, input values and output values for marginal cost figures are presented. Input and output values are presented for the EU28. Again, national values are provided in the Excel Annex.
- The robustness of the recommended input and output values are discussed.

Each of the external cost chapters in the main text has its own annex (Annex B to G), which provides:

- A more detailed discussion of the impacts of the externality (if relevant).
- A brief discussion on the methodologies and input values recommended by the previous Handbook.
- A detailed overview of recent evidence in the literature (mainly studies published since the previous version of the Handbook) on the methodology and input values to estimate the external costs, including a critical assessment of this evidence. This literature review is focussed on both total/average and marginal external costs.
- Conclusions on the best practice methodologies and input values to be recommended in this Handbook. These recommendations are compared with the recommendations made in the previous Handbook and any deviations are explained.

In addition to these external cost specific annexes, a more general annex on the economic valuation of human health is provided (Annex A). This annex provides an overview of indicators to valuate impacts on human health as well as evidence from literature on the value of these indicators. Based on this assessment, recommended approaches to valuate impacts on human health are provided. These recommended approaches are used in providing input and output values for external cost categories like air pollution, noise and accidents in a consistent way.

Finally, a synthesis of the results is presented in the last chapter of this Handbook, comparing total, average and marginal cost values between countries and transport modes. Furthermore, a brief comparison with previous studies (including the previous Handbooks) is presented.

The various costs can be added up to retrieve the total external costs per transport mode, although it should be noted that the totals per vehicle type reported in the handbook may not necessarily sum up to the total per mode due to rounding errors. Furthermore, it should be noted that this Handbook the scope for aviation and maritime shipping is a selection of EU (air)ports, while for the other modes the costs are presented for the EU28. In order to allow a cross modal comparison, also estimates for the total costs for EU28 for aviation and maritime shipping are presented, based on extrapolation of the costs for the selected (air)ports.

The user needs also to be aware that whilst in all cases the same issue is being measured in principle (what economists call the external social welfare impacts), the nature of the various cost categories is different and therefore different methodologies were used.

1.5 Outline of the Handbook

Chapter 2 of this Handbook first provides a general methodological framework for the estimation of external costs. It defines external costs and briefly discusses the main methodologies to estimate them. The recommended methodologies, input values and output values for the various external cost categories are presented in Chapters 3 to 9. In Chapter 10, some external cost categories for which no quantitative assessment can be applied (due to a lack of scientific evidence) are discussed in qualitative way. Finally, the main conclusions and recommendations for further research are presented in Chapter 11.

2 General methodological framework

2.1 Introduction

In this chapter we present the general methodological framework to estimate the external costs of transport. We start by discussing the concept of external costs in Section 2.2. In this section we provide a general definition of external costs, explain the differences between total, average and marginal external costs and discuss the level of externality of different types of external costs. In Section 2.3 we provide a general overview of the valuation methodologies that can be used to estimate external costs, discussing their main pros and cons. Finally, in Section 2.4, we explain the procedure for transferring values from one country to another or over time.

2.2 The concept of external costs

External costs, also known as externalities, arise when the social or economic activities of one (group of) person(s) have an impact on another (group of) person(s) and when that impact is not fully accounted, or compensated for, by the first (group of) person(s). In other words, external costs of transport are generally not borne by the transport user and hence not taken into account when they make a transport decision. Cars exhausting NO_x emissions, for example, cause damage to human health, imposing an external cost. This is because the impact on those who suffer damage to their health is not taken into account by the driver of the car when deciding on taking the car.

External costs of transport refer to the difference between social costs (i.e. all costs to society due to the provision and use of transport infrastructure) and private costs of transport (i.e. the costs directly borne by the transport user). As the market does not provide an incentive to transport users to take external costs into account, they only take part of the social costs into account when taking a transport decision, resulting in sub-optimal outcomes. By internalising these costs, externalities are made part of the decision making process of transport users. This can be done through regulation (i.e. command and control measures) or by providing the right incentives to transport users, namely with market based instruments (e.g. taxes, charges, emission trading, etc.). A combination of these two basic types of instruments is possible, e.g. taxes differentiated to Euro emission classes of vehicles.

Using market-based instruments to internalise external costs is generally regarded as an efficient way to limit the negative side effects of transport and/or to generate income for the government. Applying these instruments in an efficient way requires detailed and reliable estimates of external costs. Also for other applications (e.g. use in Cost Benefit Analyses), external cost figures are useful parameters.

Total, average and marginal external costs

Different types of external costs are distinguished in this Handbook:

- *Total external costs* refer to all external costs within a geographical boundary (e.g. EU28 or a country) caused by (a specific mode of) transport. Total external costs are usually presented in billions or millions Euros.
- *Average external costs* are closely related to total costs, as they express the costs per transport performance unit[3]. In this study average external costs are generally presented in €-cent/pkm, €-cent per tkm and/or €-cent/vkm. For some transport modes/externalities alternative units are used, e.g. €-cent/LTO (aviation) or €-cent per port call (maritime transport).
- *Marginal external costs* are the additional external costs occurring due to an additional transport activity. In the short run, these costs are linked to constant infrastructure capacity, whereas long run marginal costs do take the construction of additional traffic infrastructure into account. This implies, for example, that short run marginal congestion costs are, in general, higher than long run marginal congestion costs. As short run marginal cost figures are more relevant for internalisation purposes, they are the main focus of this Handbook. Generally, marginal external costs are presented in the same units as average external costs (e.g. €-cent/pkm, €-cent/tkm, €-cent/vkm).

For some externalities (e.g. air pollution, climate change) average and marginal cost figures are (approximately) equal to the size of the externality and do not depend on the density of the traffic flow. A car entering a dense traffic flow emits the same amount of air pollutant emissions as a car entering a thin traffic flow, assuming that all other factors are equal (location, speed, etc.). However, for other externalities (e.g. accidents, noise, and congestion) the costs do depend on the density of the traffic flow. For example, a car entering a road with free flow traffic, will cause marginal external congestion costs that are significantly lower than the average external congestion costs. However, when a car enters the traffic flow, at the moment the capacity of the road is almost met, it will cause marginal external congestion costs that are significantly higher than the average costs.

Whether average or marginal external costs figures should be used depends on the scope and objective of the assessment for which the figures will be applied. For assessments on the internalisation of external costs, marginal cost figures should be considered when internalisation is considered from an economic efficiency point of view (marginal social cost pricing). However, from an equity point of view, it may be more interesting to see whether vehicles are charges at their average costs (‘average cost pricing’), ensuring that the transport sector or vehicle categories pay for the costs they impose on society. Average and marginal external costs may also be used for other purposes, e.g. social cost benefit analyses, cost-effectiveness analyses of other welfare economics analyses. In these cases, it depends on the actual scope of such analyses whether the appliance of marginal or average cost figures is preferred. For example, for a social cost benefit analysis of the realisation of a new road, the noise costs can best be estimated by average cost figures (as there is no existing traffic situation). On the other hand, for a social cost benefit analysis of an extension of a road from two to four lanes, the use of marginal cost figures is preferred (as the change in an existing traffic situation is assessed).

[3] In other words, average costs are calculated by dividing the total costs by the total transport performance.

Level of externality

As mentioned above, external costs are the difference between social and private costs. Table 3 provides an overview of the social and external costs for the main cost categories considered in this Handbook. The level of externality differs between these cost categories:

- For congestion and scarcity costs only the additional costs for other transport users and society are considered external in this Handbook. Own costs (e.g. additional travel time or fuel costs) are private costs and hence are not considered when estimating external congestion costs. With respect to total and average congestion costs, it should be noted that part of the costs are borne by the same group as those cause the congestion (the so-called club effect). For example, the total external congestion costs of passenger cars do include costs borne by users of passenger cars who are delayed because other passenger cars have entered the traffic flow. As marginal costs are considered from an individual transport user perspective, club effects do not occur.
- Part of the social costs of accidents are internalised by the transport user (i.e. as they consider their own accident risk when taking a transport decision, it may be argued that their own accident costs are internalised) or by insurances. As for congestion, part of the total/average external accident costs are borne by the same group of agents who cause the accident costs.
- For environmental costs the external and social costs are the same, except for the situation in which part of the social costs are charged for. However, as we do not consider transport charges and taxes in this Handbook (they are considered separately in a parallel study, see the text box in Section 1), we can assume (in general) that social and external environmental costs are the same.

Table 3 – Level of externality of various costs categories

Cost category	Social costs	External costs
Congestion costs and scarcity costs	All costs for traffic users and society (delay, unreliable travel times and/or arriving times, additional operation costs, missed economic activities) caused by high traffic densities given the available capacity of the infrastructure.	Additional costs imposed on all other transport users and society excluding own additional costs.
Accident costs	All direct and indirect costs of an accident (material costs, medical costs, production losses, suffering and grief caused by fatalities and injuries).	Part of the social costs that is not considered in own and collective risk anticipation and not covered by (third party) insurance.
Environmental costs	All damages of environmental nuisances (e.g. health costs, material damages, biosphere damages, long term risks).	Part of the social costs that is not considered (paid for).

2.3 General overview of valuation methodologies

Externalities are, in general, not traded on actual markets and hence no market prices are available for them. Therefore, alternative valuation methodologies have to be applied to quantify external costs. Several methodologies can be used for the valuation of externalities. The main ones are the damage cost approach, the avoidance cost approach and the replacement cost approach. These are discussed in more detail hereafter.

Damage cost approach

The preferred option by economists to value external costs is the damage cost approach (Botzen & Van den Bergh, 2012). This approach values all damage experienced by individuals as a result of the existence of an externality (e.g. health impacts due to traffic noise). As market prices are often unavailable for the damage experienced, the willingness to pay (WTP) of individuals to (partly) avoid the damage or the willingness to accept (WTA) the damage, is used as an indicator of individual preferences.

There are several methods available for estimating the WTP, falling broadly into two categories:

- *Stated preference* (SP) methods use questionnaires or experiments where respondents are asked to provide their WTP (or WTA) to avoid the damage of the externality. SP methods can take two forms: contingent valuation (through use of questionnaires or surveys, where respondents are directly asked for their WTP for a certain good) and choice experiments (where respondents are asked to pick their most favoured alternative from different packages, and WTP is inferred indirectly). SP methods directly measure the WTP and they also allow the researcher to control for all external factors, such that purely the externality considered is identified. On the other hand, SP methods depend very much on the survey/experiment design and the level of information, and it suffers from the fact that it involves hypothetical expenditures only. Also avoiding strategic behaviour of respondents is a main challenge of these kind of studies.
- *Revealed preference (RP)* methods deduce the monetary value of externalities from transactions on other economic markets, e.g. the real estate market. The most commonly used RP method is the hedonic price method, which uses price differences on the house market to estimate the WTP for the reduction of transport noise or emissions. The main strength of RP methods is that it relies on actual market behaviour, where individuals' WTP for avoiding a specific externality can be observed. However, the results from RP studies are sensitive to the conditions of the markets observed. Furthermore, lack of knowledge of the market actors on the damage caused by the externality may seriously affect the reliability of the results of RP studies.

In this Handbook damage costs are applied for several external cost categories, including air pollution, accidents and noise.

Avoidance cost approach

An alternative way to value external costs is by applying the avoidance cost approach. In this Handbook the CO_2 price that is used to calculate the external costs of climate change is based on this approach. The avoidance cost approach determines external cost valuation factors (i.e. shadow prices) by determining the cost to achieve a particular policy target (e.g. EU CO_2 reduction targets). This is done by estimating an avoidance cost function, which provides a proxy for the supply of environmental quality. It determines how much it would cost to supply an additional level of environmental quality (e.g. reduction of one additional tonne of CO_2). Based on this cost curve, the minimal cost required to meet the policy target is estimated. The assumption is that this policy target reflects collective preferences with respect to the externality concerned and hence, that the minimum cost to reach this target is a good proxy of the (collective) WTP to avoid the damage caused by the externality.

The avoidance cost approach is particularly useful when the damages caused by the externality are uncertain and/or difficult to measure. In these cases the avoidance cost approach may provide more reliable cost values in a relatively simple way. On the other hand, the avoidance cost approach is often criticized due to policy targets not always being a good reflection of the individual (or collective) preferences of citizens.

Replacement cost approach

The replacement or repair cost approach estimates the value of an externality based on the costs of replacing/repairing the adverse impacts caused by the externality. In this Handbook the replacement cost approach have been used to estimate the costs of habitat damage. This approach is often used to value external costs for which no reliable damage or avoidance cost figures are available. It may result in an overestimation, as it is not always economically efficient to repair all damage. On the other hand, the replacement cost approach may also underestimate the actual value of external costs, as it is not always possible to replace/repair all damage.

2.4 Value transfer approach

The input and output values estimated in this Handbook are collected from various studies which estimate Willingness to Pay (WTP) values for the different externalities under the particular conditions of the location and in the specific time period of the studies. To be used across the different Member States and countries considered in this Handbook, a value transfer procedure is applied to convert the estimated values from the 'study site' to 'other sites'. The value transfer procedure provides an alternative to carrying out valuation studies in all the different Member States and countries and could fill in any gaps where country or regional values are not available from primary sources[4]. The value transfer approach can also be used to transfer the input and output values as presented in this Handbook to other countries or other years.

Overview value transfer approaches

Different approaches exist to undertake a value (or benefit) transfer procedure (NEEDS, 2009):
- Unit Value Transfer:
  - Simple unit transfer.
  - Unit Transfer with income adjustments.
- Function Transfer:
  - Benefit Function Transfer.
  - Meta-analysis.

The unit value transfer procedure consists of transferring the primary data from the original location directly to the new location. This can either be a direct transfer (simple unit transfer) or with slight adjustments, such as exchange rate, inflation and income (unit transfer with income adjustments). The benefit function transfer approach consists of estimating a function that establishes the relationship between the unit value and the characteristics at the original site in order to predict the values at another site. Although theoretically superior due to it taking more information into account, the benefit

[4] Considerations should be made here on the purpose of the analysis, see Ready & Navrud (2006).

function transfer approach tends to be more complex to apply in practice, because it requires information on each of the characteristics at the new site.[5] For example, the willingness to pay to reduce noise may be estimated by figures on income, population density and age. To approximate the willingness to pay for noise reduction in a different region, statistics will need to be collected for income, population density and age. Another possibility is to carry out a meta-analysis of several valuation studies to estimate a common benefit function. This approach also presents its challenges such as the lack of relevant information and studies. For these reasons, the unit value transfer with income adjustment is preferred for its simple, transparent and reliable results[6]. This was the approach followed in the previous Handbooks and is applied in this revision.

Recommended approach: unit value transfer with income adjustments

Transferring the unit value from the original country to the remaining Member States and countries considered in this Handbook requires the following adjustments which control for differences across locations:

- *Differences in prices*. Controlling for differences in prices is crucial to minimise errors when transferring values across locations. The recommended approach is to use *PPP-corrected exchange rates* to take into account the cost of living. If appropriate, adjustments can also be made in line with differences in living costs between regions within the same country.
- *Differences in income*. A central issue when converting values between countries is to consider differences in income. The common approach consists of multiplying the unit values by the ratio of income in the policy country to income in the study country as such:

  $$WTP_{PS} = WTP_{SS}\left(\frac{I_{OS}}{I_{SS}}\right)^{\varepsilon},$$

  Where WTP_{PS} is the WTP transferred to the study site, WTP_{SS} is the WTP at the study site, I_{OS} and I_{ss} are income at the other and study sites, and ε is income elasticity of WTP. Income is defined as PPP-adjusted GDP/capita in this Handbook[7]. For the income elasticity a value of 0.8 is recommended, indicating that environmental goods can be considered normal goods. This value of the income elasticity is based on an extensive meta-analysis of the OECD, which concludes that the income elasticity for the WTP of environmental and health related goods falls between 0.7 and 0.9.
- *Other differences*. Input and output values can be further adjusted based on the specific characteristics of the externality. For example, accident costs should be adjusted according to accident risk rates. The specific value transfer procedure carried out for each type of externality is discussed in the relevant chapters.

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[5] Associated to challenges such as low explanatory power due to omitted variables; extrapolating outside range of the data; variation among individuals not the same as variation among countries; functional form choice, etc.

[6] Bateman et al., 2002; OECD, 2011a; Czajkowski et al., 2017.

[7] Other income indicators could be used alternatively. Czajkowski and Ščasný (2010) found that using site-specific measures of income outperforms transfers based on GPD per capita. Ready & Navdrud (2006) provide a discussion on the key considerations. We have chosen GDP/capita as this is a widely available indicator and used by several studies, including the previous Handbook.

Unit value transfer is not only used to transfers input and output values between countries, but also over time. The following adjustments have to be made for this purpose:

- *Difference in price level*. Consumer Price Indexes (CPI) should be used for this purpose, which produces conservative estimates.
- *Difference in income*. Income levels generally increase over time. This implies that the WTP also increases, assuming that externalities can be considered as normal economic goods. Therefore the same correction used for the value transfer between countries can be used. It may be argued that the income elasticity for temporal transfers is lower than for spatial transfers, particularly as there may be diminishing marginal returns on the WTP for health improvements in developed countries[8]. However, as there is no clear evidence for this statement in the literature, we recommend to apply the same elasticity for spatial and temporal value transfers (i.e. 0.8).

[8] As the average life expectancy of people increase over time, it may be that the WTP to increase this life expectancy even longer may decrease. Particularly as the probability of additional life years with bad health conditions grows as life expectancy increases.

3 Accident costs

3.1 Introduction

Accidents occur in all forms of traffic and result in substantial costs, consisting of two types of components: material costs (e.g. damages to vehicles, administrative costs and medical costs) and immaterial costs (e.g. shorter lifetimes, suffering, pain and sorrow).
Market prices can be used to calculate material costs, however, no such market prices exist for immaterial costs. In addition, a part of the total accident costs are already internalised, for example through insurance premiums or through accounting for risks that are well anticipated.

In this chapter we provide an overview of the recommended approaches to value external accident costs. In Section 3.2 we first briefly discuss the definition and scope of accident costs. The total and average accident costs are presented in Section 3.3, and the marginal accident costs are the topic of Section 3.4. Finally, the robustness of the accident cost figures presented in this chapter is analysed in Section 3.5. More detailed information on accident costs can be found in Annex B.

3.2 Definition and scope

Although there is no harmonised definition of external accident costs, we define them as the social costs of traffic accidents that are not covered by risk oriented insurance premiums in this edition of the Handbook. The insurance system therefore determines the share of the accident costs that are considered internal. Any costs that are covered by insurances are therefore not considered external to the individual (i.e. they are internalised). Costs that are not covered by insurances are external. This approach is in line with earlier editions of the Handbook, although it is important to acknowledge that studies at the national level may use a different distinction. For a full discussion we refer to Annex B.

There are five main components of accident costs:
- *Human costs:* This is a proxy for estimating the pain and suffering caused by traffic accidents in monetary value. In cases of injuries it covers the victim's pain and suffering, in cases of fatalities it covers the victim's loss of utility. Traffic participants are assumed to be aware of the fact that their decision to enter the traffic may result in an accident (they internalise this risk). Therefore, their own human costs are considered internal to them, once they have made the decision to enter the traffic. However, they consider the human costs of others that may result from their own transport decision as external to them.
- *Medical costs:* These are the costs of the victim's medical treatment provided by hospitals, rehabilitation centres, general practitioners, nursing homes, etc. as well as the costs of appliances and medicines. The medical costs cover the time period from the moment of the accident until complete recovery from the injury or, in the case of fatal accidents, death. In many cases a part of these costs is already internalised

through health insurance premiums.[9] In this Handbook we assume 50% of the medical costs are external.
- *Administrative costs:* These are the costs covering the expenses of the deployed police force, fire service and other emergency (non-medical) services that assist at the crash location site. In addition, costs related to the administration of justice such as legal costs, the costs of prosecution of offenders and the costs of lawsuits and insurance are incorporated into this category. Lastly, administrative costs related to vehicle, health or other insurance is also included in this category. This component is assumed to be partly internalised by traffic participants in the form of insurance. In this Handbook we assume 30% of the administrative costs are external.
- *Production losses:* After an accident victims are not directly capable of returning to work, and in some cases may never return to work. These costs consists of the net production losses due to reduced working time and the human capital replacement costs. Not being able to carry out non-market work such as household work or volunteering is also incorporated in this cost component. This component is assumed to be partly internalised by traffic participants in the form of insurance. Based on (ARE, 2018), we assume that 55% of the gross production loss (as reported by SafetyCube) can be regarded as external.
- *Material damages:* This consists of the monetary value of damages to vehicles, infrastructure, freight and personal property resulting from accidents. This component is assumed to be fully internalised by traffic participants through insurance.
- *Other costs:* This category covers the costs of congestion resulting from road crashes, vehicle unavailability and funeral costs. We will not take this cost category into account as a large part of the *other costs* are already incorporated in other external cost categories investigated in this study or are not considered external.[10]

It is important to realise that costs related to the prevention or avoidance of crashes are not included in accident costs. Prevention costs, e.g. police enforcement costs, are not included because they are not a (direct) consequence of road crashes, but are intended to decrease the number of crashes (Wijnen, et al., 2017). Furthermore, these are (partly) included in road infrastructure costs in (CE Delft et al., Forthcoming).

Fatalities and injuries

In this study, we present the external accident costs for all five modes of transport (road, rail, aviation, IWT and maritime). The victims of traffic accidents are classified into one of three categories: fatalities, severe injuries and slight injuries. This is done based on the definitions in (UN ECE, 2011).
- *Fatality:* Any person killed immediately or dying within 30 days as a result of an injury sustained as a result of an accident.
- *Serious injury:* A person who sustained an injury as a result of the accident and who was hospitalised for a period of more than 24 hours.
- *Slight injury:* A person who sustained an injury as a result of the accident but does not fall under the definition of serious injury.

[9] Please note that there are large differences in the health insurance systems across countries in the EU, e.g. in terms of deductibles. In general we have assumed that health insurance is a way to (partly) internalise the health costs, without taking the nuances of the different national health care systems into account.

[10] For instance, congestion costs fall under ‘other costs’ but are already included as another category in this handbook. Other costs such as funeral costs may already be (partly) insured, which no longer renders them (fully) external.

However, it is important to note that EU countries started collecting data on injuries from traffic accidents using a new common definition in 2014. This scale, the Maximum Abbreviated Injury Scale (MAIS), is based on the most severe injury in the Abbreviated Injury Scale (AIS) classification system commonly used by medical professionals. The use of this scale will result in it being easier to classify accident data according to the right category, as this is the classification system adhered to by hospitals in Europe. This also means the data between countries will become more harmonised and consistent. The MAIS represents the most severe injury obtained by a casualty according to the AIS. Serious traffic injuries are now classified as injuries scoring 3 or more on the medical Maximum AIS (MAIS3+). Therefore, for traffic injury victims MAIS 1 and MAIS 2 are considered slight injuries.

Table 4 - Comparison of old and new EU traffic injury definitions

AIS scale		Example	Old definition
AIS 1	Minor	Sprained ankle	Slight injury
AIS 2	Moderate	Closed fracture	
AIS 3	Serious	Open fracture	Serious injury
AIS 4	Severe	Amputation	
AIS 5	Critical	Ruptured liver with tissue loss	
AIS 6	Maximum	Unsurvivable injury	Fatality

However, figures on the number of seriously injured people according to the new definition are not yet available for all countries (and not at the same level of detail comparable to the old definition). Therefore, the estimation of external accident costs in this Handbook will be based on accident figures according to the old definition. However, we do propose some input values for the new definition of injuries in Annex B.3.2.

It is worth noting that the number of fatalities and injuries in official statistics only represent reported accidents. However, for road accidents in particular, a portion of the total accidents go unreported. Therefore, the official road accident data ought to be corrected for these unreported accidents. The correction factors that are applied in this study are shown in Table 5, and are based on (HEATCO, 2006), a large EU study, and a Swiss (Ecoplan, 2002) study. One minor adjustment was made to these correction factors, the underreporting rate for fatalities was 1.02 in HEATCO & Ecoplan, but a study by (Ecoplan & Infras, 2014) revealed that there are no longer unreported fatalities from accidents in Switzerland. We assume that this also holds for the rest of Europe, therefore, the rate for fatalities has been adjusted to 1.00 (i.e. no underreporting). Previous editions of the Handbook used the correction factors presented in Table 5 for serious and slight injuries, but used a factor of 1.02 for fatalities.

Table 5 - Correction factors to correct for underreporting of accidents

	Fatalities	Serious injury	Slight injury
Car, LCV, HGV, bus	1.00	1.25	2.00
Motorbike	1.00	1.55	3.20

Source: **(HEATCO, 2006)** & **(Ecoplan, 2002)**.

The underreporting factors in Table 5 shows that the underreporting rate differs depending on the vehicle type and the severity of the accident, with more vulnerable road users such as motorcycles having higher unreported accidents than less vulnerable road users (e.g. HGVs, buses).

Although the reporting factors are old, there are no more recent studies looking at underreporting rates at the international level. Studies at the national level confirm that the factors displayed in Table 5 are reasonable. For instance, studies looking at Korea show that there are four times as many road traffic victims reported by data from insurance agencies than there are victims reported by the police (OECD, 2016; Park, 2008).
Other studies at the national level report slightly lower underreporting rates than the Korean values, e.g. 40-45% underreporting in Australia (Rosman, 2001) and 36% underreporting in the UK (Mackay, 2003). One recent study even looked at vulnerable road users in particular and revealed that only 35% of serious injuries with motorcycles are reported, whereas only 10% of slight injuries are reported (Janstrup , et al., 2016). All in all, it appears that even though the correction factors from HEATCO are old, there are no indications that they are outdated.

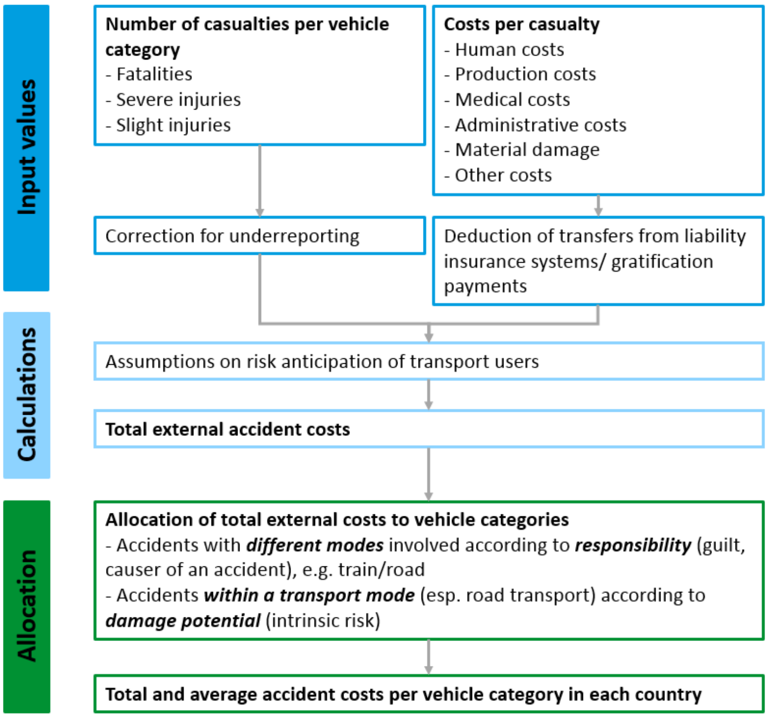
For the other transport modes such as rail, inland waterway, maritime or aviation, we do not use correction factors, as accidents occurring in these transport modes are much less likely to go unnoticed.

3.3 Total and average accident costs

3.3.1 Methodology

Total and average accident costs are calculated using a top-down approach, starting with total accidents and then allocating them to different vehicle types. Figure 1 illustrates the corresponding methodology for calculating accident costs for road, rail, inland waterway, maritime and aviation.

Figure 1 – Methodology total and average accident costs



The main input values that are used are the number of casualties per vehicle category and the costs per category. For the number of casualties per vehicle category in road transport, we use detailed statistics from the CARE database which also provides information on the other parties involved in the accident. For the other modes, data to that level of detail is not available. The data provided for rail accidents already excluded suicides.
The cost per casualty consists of six components, of which four (human costs, production costs, medical costs and administrative costs) are (partly) external. By multiplying the number of casualties by the cost per casualty and deducting the transfers from liability insurance systems and gratification payments the total external accident costs are estimated.

Allocation to the different vehicle categories is carried out according to damage potential (intrinsic risk) if the accidents occur within one transport mode. This method is used in studies such as (CE Delft & VU Amsterdam, 2004; CE Delft, INFRAS & Fraunhofer ISI, 2011).[11] The method involves allocating the victims in the opposing vehicle to the other vehicle type involved in the crash and vice versa. For instance, if a fatal accident occurs between a HGV and a car, and the driver of the HGV sustains a slight injury whereas the driver of the car dies, the cost of the fatality is allocated to the truck, whereas the cost of the slight injury is allocated to the car.

For accidents between different modes, such as accidents involving a train and a car, the casualties are allocated to the party responsible for the accident. In this study, these types of accidents only occur between road and rail, at level crossings. For these types of accidents it is known that they are almost always caused by the road user (Jonsson & Björklund, 2015)[12]. These steps result in the total and average accident costs per vehicle category in each country.

3.3.2 Input values

Accident statistics

The accident statistics that are used for road transport are taken from the EU's Community Road Accident Database (CARE). This highly detailed database provides information on fatalities, serious injuries and slight injuries, in which vehicle these victims were seated, and which other vehicle was involved in the accident at the country level. Statistics are further split according to road type (urban, rural, motorway and unknown). Because of the different vehicle types within this transport mode, such detailed data is needed in order to allocate the costs to the vehicle types according to the vehicle type's damage potential (intrinsic risk).

The previous Handbook did not include data on the accident costs of the other transport modes. In this Handbook we do estimate these costs, although the available data is not as detailed as the CARE database is for road transport. For these modes, accidents are not as frequent as for road transport, which is why we use averages over 5 years (2012-2016).
For rail transport, the accident statistics were provided by the European Union Agency for Railways (ERA). However, the ERA does not collect figures for slight injuries, so the rail external accident costs are only based on fatalities and serious injuries, and will therefore

[11] There are two other approaches which could alternatively be used, which are elaborated in more detail in Annex B.

[12] Please note that if the damage potential approach would be used instead of the responsibility perspective this would result in accident costs that are only very minorly different from the responsibility approach.

be an underestimate. Suicides were excluded from the rail accident data by the ERA. For aviation the total statistics for the EU28 are provided by European Aviation Safety Agency, from which an accident rate per movement could be deduced. By combining this with information on the number of flight movements per airport, the total number of casualties could be calculated per airport. Please note that these are not the actual casualties that occurred in that period, but a proxy for the risk. For inland waterways the accident rate per 1,000 vkm is based on data from the Dutch Department for Waterways and Public Works. These accidents are also a proxy for the risk of inland waterway transport, rather than the actual accidents that occurred in the period considered. For maritime transport, accident statistics were provided by the European Maritime Safety Agency. These are the actual accidents that occurred over the time period considered.

Costs per casualty

The various components of the costs per casualty are largely based on SafetyCube (2017), which estimates standard values for each of the cost components according to the methods outlined in the international guidelines developed by (Alfaro, et al., 1994). The values presented in (Wijnen, et al., 2017) are the social costs of accidents, not the *external* costs of accidents, and therefore need to be corrected.

The only cost component in our calculation that is not based on SafetyCube is the human cost, the largest part of accident costs. The human costs are valued based on the Value of Statistical Life (VSL), which we base on the (OECD, 2012). A detailed discussion on the VSL is presented in Annex A. The EU28 VSL used is € 3.6 million. To avoid double counting with gross production loss, the consumption loss needs to be deducted from the VSL to reach human costs for fatalities (see Section B.3.2). Consumption loss is calculated by combining data on the consumption expenditure per capita per annum with the amount of life years lost due to an accident (on average 42 years). This results in an EU28 average consumption loss for a fatality of € 668,000. Therefore, the human costs of fatalities for the EU28 is € 2.9 million. The human costs of injuries are valued at 13% and 1% of the VSL respectively for serious and slight injuries (HEATCO, 2006). No consumption loss is deducted from the values for injuries.

Table 6 – External accident cost components per casualty for the EU28 ($€_{2016}$)

	Human costs	Production loss	Medical costs	Administrative costs	Total external cost per casualty
Fatalities	2,907,921	361,358	2,722	1,909	**3,273,909**
Serious injuries	464,844	24,055	8,380	1,312	**498,591**
Slight injuries	35,757	1,472	721	564	**38,514**

Table 7 - External accident costs components per casualty for the EU28 (€2016)

	Human costs			Production loss			Medical costs			Administrative costs		
	Fatality	Serious injury	Slight injury	Fatality	Serious injury	Slight injury	Fatality	Serious injury	Slight injury	Fatality	Serious injury	Slight injury
EU countries												
EU28	2,907,921	464,844	35,757	361,358	24,055	1,472	2,722	8,380	721	1,909	1,312	564
AT	3,202,976	532,685	40,976	393,002	26,161	1,600	2,960	9,114	784	2,076	1,427	614
BE	3,183,342	513,206	39,477	394,570	26,266	1,607	2,972	9,151	788	2,084	1,433	616
BG	1,553,981	226,042	17,388	172,290	11,469	702	1,298	3,996	344	910	626	269
HR	2,308,933	334,147	25,704	230,091	15,317	937	1,733	5,336	459	1,215	836	359
CY	1,504,105	285,078	21,929	319,468	21,266	1,301	2,406	7,409	638	1,687	1,160	499
CZ	2,789,348	406,295	31,253	236,108	15,717	962	1,778	5,476	471	1,247	858	369
DK	3,497,489	576,978	44,383	485,139	32,295	1,976	3,654	11,251	968	2,562	1,762	757
EE	2,653,497	391,365	30,105	264,696	17,620	1,078	1,994	6,139	528	1,398	961	413
FI	2,798,583	475,746	36,596	444,438	29,585	1,810	3,348	10,307	887	2,347	1,614	694
FR	2,721,569	449,900	34,608	395,712	26,342	1,612	2,981	9,177	790	2,090	1,437	618
DE	3,067,253	503,575	38,737	383,018	25,497	1,560	2,885	8,883	765	2,023	1,391	598
EL	2,026,599	328,432	25,264	296,552	19,741	1,208	2,234	6,877	592	1,566	1,077	463
HU	2,545,519	363,132	27,933	213,101	14,186	868	1,605	4,942	425	1,126	774	333
IE	4,681,432	710,688	54,668	398,560	26,531	1,623	3,002	9,243	796	2,105	1,448	622
IT	2,888,866	468,373	36,029	354,695	23,611	1,444	2,672	8,226	708	1,873	1,288	554
LV	2,091,145	314,437	24,187	244,097	16,249	994	1,839	5,661	487	1,289	887	381
LT	2,472,609	368,941	28,380	221,664	14,756	903	1,670	5,141	442	1,171	805	346
LU	6,048,974	955,627	73,510	436,719	29,071	1,779	3,289	10,128	872	2,307	1,586	682
MT	1,726,048	292,090	22,468	294,266	19,589	1,198	2,216	6,824	587	1,554	1,069	459
NL	3,144,379	506,503	38,962	400,833	26,683	1,632	3,019	9,296	800	2,117	1,456	626
PL	2,209,087	322,671	24,821	201,159	13,391	819	1,515	4,665	402	1,062	731	314
PT	2,249,642	359,065	27,620	287,703	19,152	1,172	2,167	6,672	574	1,520	1,045	449
RO	2,257,137	322,445	24,803	183,549	12,219	747	1,383	4,257	366	969	667	287
SK	2,602,350	381,986	29,384	240,873	16,034	981	1,814	5,586	481	1,272	875	376
SI	2,127,862	337,228	25,941	293,677	19,549	1,196	2,212	6,811	586	1,551	1,067	459
ES	2,690,282	427,815	32,909	325,423	21,663	1,325	2,451	7,547	650	1,719	1,182	508
SE	2,819,502	476,827	36,679	470,659	31,331	1,917	3,545	10,915	939	2,486	1,709	735
UK	2,448,105	442,196	34,015	420,407	27,986	1,712	3,167	9,750	839	2,220	1,527	656
Non-EU countries												
NO	2,860,780	523,348	40,258	535,129	35,622	2,179	4,031	12,410	1,068	2,826	1,944	836
CH	3,860,318	707,624	54,433	554,838	36,934	2,260	4,179	12,867	1,107	2,930	2,015	866
CAN-AL	3,487,874	453,424	34,879	419,350	27,915	1,708	3,159	9,725	837	2,215	1,523	655
CAN-BC	3,487,874	453,424	34,879	419,350	27,915	1,708	3,159	9,725	837	2,215	1,523	655
US-CA	3,984,276	517,956	39,843	443,577	29,528	1,806	3,341	10,287	885	2,343	1,611	693
US-MO	3,984,276	517,956	39,843	443,577	29,528	1,806	3,341	10,287	885	2,343	1,611	693
JP	3,400,821	442,107	34,008	409,621	27,268	1,668	3,085	9,500	818	2,163	1,488	640

3.3.3 Output values

Table 8 describes the total and average external accident costs in the EU as a whole for road and rail transport. Costs at the country level are provided in the database.

Table 8 - Total and average external accident costs for land-based modes for the EU28

Transport mode	Total costs EU28	Average costs	
Passenger transport	**Billion €**	**€-cent per pkm**	**€-cent per vkm**
Passenger car	210.2	4.5	7.2
Motorcycle[13]	21.0	12.7	13.3
Bus/Coach	5.3	1.0	18.9
Total passenger road	**236.5**		
High speed passenger train	0.1	0.1	17.3
Conventional passenger train	2.0*	0.5	52.2
Total passenger rail	**2.0**		
Total passenger transport	**238.5**		
Freight transport	**Billion €**	**€-cent per tkm**	**€-cent per vkm**
LCV	19.8	6.0	4.1
HGV	23.0	1.3	15.5
Total freight road	**42.8**		
Freight train	0.3	0.1	34.1
Inland Vessel	0.1	0.1	86.3
Total freight transport	**43.1**		
Total road, rail, inland waterway	**281.7**		

* Total costs without highspeed passenger trains (average costs for passenger train electric: incl. high speed trains).

Average costs are calculated by dividing the total costs by the transport performance data. Motorcycles cause by far the highest average external accidents costs per pkm. The CARE database revealed that motorcyclists are involved in a relatively high number of accidents. This despite the fact that they drive relatively fewer kilometres with a lower occupancy rate. Therefore, this results in a higher accident costs for motorcyclists compared to cars.

Table 9 illustrates the average external accident costs of both passenger and freight aviation. Passenger aviation values are provided per LTO, passenger and pkm. The average costs of freight aviation are provided per LTO, tonne and tkm. Costs at the individual airport level are provided in the database.

Table 9 - Total and average external accident costs for aviation for 33 selected EU airports

Transport mode	Total costs	Average costs			
Passenger aviation	**Million €**	**€/LTO**	**€/passenger**	**€/tonne**	**€-cent/pkm**
Short haul	75.01	22.95	0.18	0.81	0.04
Medium haul					0.01
Long haul					0.001

* Costs per pax are including the complete flight (not only the half-way principle).

13 Please note that the costs of motorcycles does not include the costs for mopeds. Moped accidents are roughly 1% of EU fatalities and 2-3% of EU injuries. Although the CARE database has statistics available on moped fatalities, allocation to mopeds cannot be carried out as there is no transport performance data specifically for mopeds available.

Table 10 presents the average external accident costs of maritime transport. For ferries, the costs are calculated per port call, passenger and pkm. For freight maritime transport, the average external costs are provided per port call, tonne and tkm. Costs at the individual port level are provided in the database.

Table 10 - Total and average external accident costs for maritime transport for 34 selected EU ports

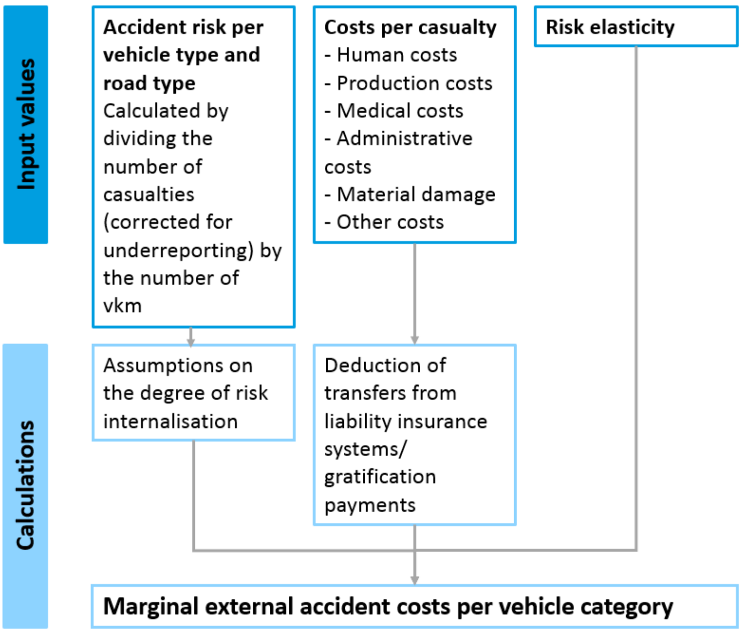
Transport mode	Total costs	Average costs	
Passenger transport	**Million €**	**€ per port call**	**€ per million passengers**
Passenger ship	3.3	26	40,996
Freight maritime transport	**Million €**	**€ per port call**	**€ per million tonnes**
Freight ship	63.3	318	36,524

3.4 Marginal accident costs

3.4.1 Methodology

Marginal accident costs are only calculated for road transport. For all other modes of transport the marginal accident costs are considered to be equal to the average costs. This is because the other modes are scheduled services, this implies that the accident risk is less dependent on the amount of traffic for these modes. Figure 2 illustrates the methodology for calculating marginal accident costs for road transport.

Figure 2 - Methodology marginal external accident costs



The marginal accident costs represent the extra costs that adding an extra vehicle to the traffic flow brings. The main input values for marginal accident costs are the accident risk per vehicle type and road type, the costs per casualty and the risk elasticity. The costs per casualty are the same as those used for the calculation of total and average costs.

Combining the accident risk with assumptions on the degree of risk internalisation, the external costs per casualty and the risk elasticity allows us the calculate the marginal external accident costs per vehicle category (see Annex B.4 for more details).

3.4.2 Input values

The input values used to calculate marginal external accident costs are largely comparable to the ones used for total and average accident costs, e.g. the costs per casualty. For these input values we refer to Section 3.3.2.

Risk elasticity

The risk elasticity represents how much the accident risk on a certain road type increases with a 1% increase in traffic measured in vkms. It is realistically expected to vary with the road type, road conditions and traffic intensity, although only very few sophisticated estimates for the risk elasticity exist, and only for individual countries. For instance, a study by (Sommer et al., 2002) looking at Switzerland found risk elasticities of -0.5, -0.25 and -0.62 for motorway, urban and other roads respectively. Rougher estimates of -0.25 irrespective of the road type were used in (Ricardo-AEA, TRT, DIW Econ & CAU, 2014; Lindberg, 2001). All suggested risk elasticities are negative, implying that although an increase in traffic increases the risk of an accident, the risk of an accident injury or fatality decreases (Hesjevoll & Elvik, 2016). However, one could argue this is not necessarily true for urban roads, where congestion and already slow traffic imply that the addition of an extra vehicle will not lead to a significant change in the accident risk (i.e. risk elasticity of 0). This is the approach taken in (CE Delft & VU, 2014). Therefore, the recommended approach in this study is to use a risk elasticity of 0 for urban roads, and -0.25 for motorways and other roads.

Degree of risk internalisation

The degree of risk internalisation is important in determining the share of the human costs that is internalised by road users. This factor differs per vehicle type, as some vehicles are simply more vulnerable than others. Therefore, the best way to reach the degree of risk internalisation is to calculate it from statistics from the CARE database. It is calculated by dividing the number of fatalities inside a certain type of vehicle by the number of fatalities in accidents involving this vehicle type (also counting victims inside other types of vehicles involved in the accidents). This gives a good indication of a vehicles 'vulnerability' compared to other vehicle types. Please note that this approach implies that in cases where there are more than one passenger in the vehicle (i.e. not only the driver) the human costs of all these passengers are fully internalised by the (driver of the) vehicle. If a vehicle then causes a fatal crash with another vehicle that has four passengers, the human costs of all of the four passengers are fully external to the original vehicle. The value for the degree of risk internalisation ranges between 0 and 1, with relatively lower values representing a smaller share of the costs is internalised. People in passenger cars and on motorcycles are expected to have a relatively higher share of the costs internalised (value closer to 1) than people inside HGVs.

Table 11 – Degree of risk internalisation for different vehicle types

Vehicle type	Risk internalisation factor
Passenger car	0.61
Motorcycle	0.93
Bus	0.16
Coach	0.16
LCV	0.28
Heavy Goods Vehicle	0.14

It is important to note that the risk elasticity (E) and the degree of risk internalisation (θ) combined lead to interesting results. If $\theta - E > 1$, the marginal costs are negative (Ricardo-AEA, TRT, DIW Econ & CAU, 2014). This implies that with each vehicle entering the road the average accident costs decreases. If $\theta - E < 1$, the marginal costs are positive and the accident costs always increases with each additional vehicle. With a risk elasticity set at -0.25 (motorways and other roads), this implies that heavy goods vehicles, busses, coaches, LCVs, passenger cars and other vehicles all have positive marginal costs. In this case, negative marginal costs exist for motorcyclists.

3.4.3 Output values

Table 12 describes the marginal external accident costs for road transport in the EU28. Costs at the country level are provided in the database. The marginal external accident costs of the other four transport modes are identical to the average external accident costs.

Table 12 – Marginal external accident costs road transport for the EU28

Vehicle type	Motorway	Urban road	Other road
Passenger transport (€-cent per pkm)			
Passenger car	0.25	1.41	0.63
Motorcycle	-0.65	4.42	-3.21
Bus/coach	0.05	0.80	0.19
LCV (€-cent per vkm)			
LCV	0.37	0.76	0.84
Freight transport (€-cent per tkm)			
HGV	0.07	0.10	0.13

The interpretation of negative marginal external accident costs (i.e. for motorcyclists) is somewhat confusing. Because traffic tends to slow down with each extra driver, the traffic becomes safer for all other traffic participants. However, the extra road user has a higher accident risk (compared to no accident risk if he decides not to take part in traffic).
The moment where the risk of an accident on other traffic users reduces by less than the increase in external accident risk by the extra traffic users, negative marginal external costs arise. This also explains why negative marginal external costs arise almost exclusively for vulnerable road users such as motorcyclists, as they have almost fully internalised their own risk (see Table 11). Please note that the costs presented here are marginal *external* accident costs, and that even though they may occasionally turn negative, this does not mean that marginal accident costs are negative.

3.5 Robustness of results

We have attempted to calculate the accident costs according to the most recent and high quality evidence and methods. In this Handbook, the accident costs calculations are much more detailed than in previous editions. Nonetheless, there are a few aspects that merit a point of discussion regarding the robustness of the results presented in this chapter.

Firstly, the human costs are the largest component of the accident costs. These costs are in turn highly dependent on the VSL that is used. We have conducted a detailed review of the literature on the VSL and found the range of values is very large. In this Handbook we have chosen to use the VSL as presented by the (OECD, 2012) as it provides the most recent high quality evidence on the VSL to our knowledge. Nonetheless it is important to emphasize that any estimate of the VSL remains uncertain. Use of the OECD VSL implies that the VSL is significantly higher in this edition of the Handbook than in previous editions (see Annex A for a full discussion), and, in turn, raises the human cost component of accident costs.

A second important uncertainty regards the percentage of the accident costs that transport users internalise in their transport decision. For the external part of human costs, we have made the assumption that one's own human costs are internalised once the decision to enter the transport is made, whereas the human costs of people in the other vehicles are considered completely external. For the other cost components, the chosen methodology implies that costs that are insured are fully internalised (see discussion in Annex B). Although there is a discussion in the literature whether insurances can be seen as a way to internalise costs, data limitations[14] imply that other methodologies are not feasible. The percentage that is internal for medical costs and administrative costs is more uncertain, due to highly diverging values found in the literature at the country level. When looking at the magnitude of these costs in comparison to the total external accident costs, the sensitivity of the total costs to the percentages used is relatively small. Varying the percentage of medical and administrative costs that is external to 100% instead of 50% (as assumed in this Handbook) only changes the total accident costs by 0.2-4%, depending on the severity of the casualty. For production loss, the percentage of costs that is external (55%) is based on one value from the literature, as there is almost no literature available on this topic. This means that 45% of production loss is covered through some form of insurance. Because production loss is the second largest cost component the percentage of production loss that is assumed external significantly influences the total accident costs. If production loss is assumed to be fully internalised, accident costs would be 4-11% lower than presented in this chapter. If production loss is assumed to be fully external, accident costs would be 3-9% higher than presented in this chapter.

Thirdly, one recent study indicated that deducting the consumption loss from the human costs to avoid double counting with the production loss should no longer be used in the calculation of external accident costs (Ecoplan, 2016). This is based on another study which concluded that there are no indications that own consumption is included in the WTP for a statistical life for Switzerland (B,S,S. Volkswirtschaftliche Beratung AG, 2015). Up until now, a cautious assumption was made that it was, which implied that net production loss (= gross production loss – consumption loss) should be used to avoid double counting. This is also the approach we have taken in this Handbook. Therefore, we have not changed the method compared to the previous editions of the Handbook. If we were to change the method, it would imply accident costs would increase by 20% per fatality, although the accident cost per serious or slight injury would not change. All in all, although we admit the

[14] This is particularly relevant in terms of large differences in the structure of different insurances in different countries, even within the EU.

(B,S,S. Volkswirtschaftliche Beratung AG, 2015) study has its merits, we believe further research is needed to confirm whether or not one's own consumption is taken into consideration when the WTP for a VSL is elicited.

Last but not least the results for road transport are affected by the transport performance data used. As explained in Section 1.3.4, in this study we use data from Eurostat, following the nationality principle, i.e. transport activity is allocated to countries where the vehicle is registered. The use of these data affects the results of this study, since the scope of these data differs from the scope of the accident data, which is in line with the territorial principle. Particularly the results for HGVs may be significantly affected at country level. For example, in countries with a lot of transit traffic (e.g. Austria) a significant part of the accidents should be allocated to foreign vehicles. By using transport performance data based on the nationality principle, transport activity of these foreign vehicles is not taken into account in the calculations.

4 Air pollution costs

4.1 Introduction

The emission of air pollutants can lead to different types of damages. Most relevant and probably best analysed are the health effects due to air pollutants. However, other damages are also relevant, such as building and material damages, crop losses and biodiversity loss.

Air pollution costs are one of the external cost categories that has been analysed the most. Since the nineties a broad range of international studies and research projects have been conducted, particularly on European level. In the last few years, there haven't been many large international studies covering the entire impact pathway from emission to impact and costs. However, epidemiological research has carried on, investigating the dose-response-relationship between the exposure of air pollutants and the associated health risks.

4.2 Definition and scope

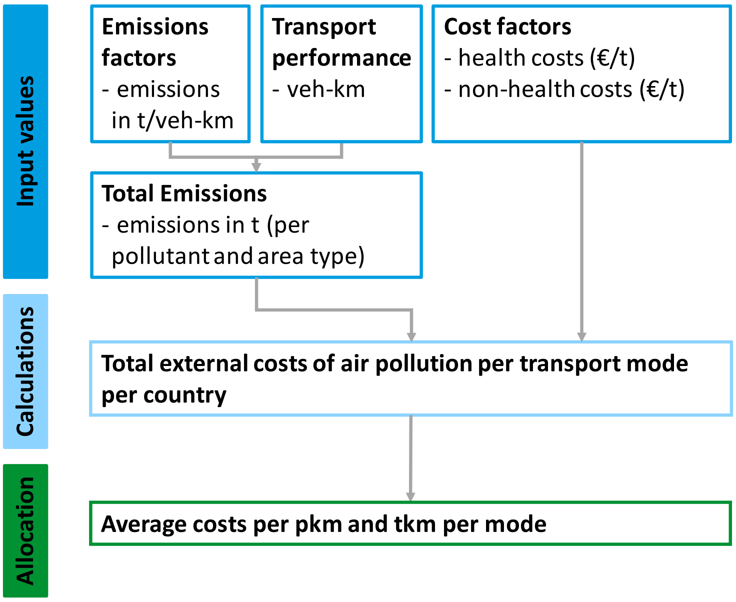
The present Handbook covers the following four types of impacts caused by the emission of transport related air pollutions:
- **Health effects:** The inhalation of air pollutants such as particles (PM_{10}, $PM_{2.5}$) and nitrogen oxides (NO_x) leads to a higher risk of respiratory and cardiovascular diseases (e.g. bronchitis, asthma, lung cancer). These negative health effects lead to medical treatment costs, production loss at work (due to illness) and, in some cases, even to death.
- **Crop losses:** Ozone as a secondary air pollutant (mainly caused by the emission of NO_x and VOC) and other acidic air pollutants (e.g. SO_2, NO_x) can damage agricultural crops. As a result, an increased concentration of ozone and other substances can lead to lower crop yields (e.g. for wheat).
- **Material and building damage:** Air pollutants can mainly lead to two types of damage to buildings and other materials: a) pollution of building surfaces through particles and dust; b) damage of building facades and materials due to corrosion processes, caused by acidic substances (e.g. nitrogen oxides NO_x or sulphur oxide SO_2).
- **Biodiversity loss:** Air pollutants can lead to damage to ecosystems. The most important damages are a) the acidification of soil, precipitation and water (e.g. by NO_x, SO_2) and b) the eutrophication of ecosystems (e.g. by NO_x, NH_3). Damages to ecosystems can lead to a decrease in biodiversity (flora & fauna).

4.3 Total and average air pollution costs

4.3.1 Methodology

Total and average air pollution costs are calculated by a bottom-up approach. Figure 3 illustrates the methodology used.

Figure 3 - Methodology total and average costs of air pollution



There are two main types of input values: the emissions and the cost factors per tonne of pollutants.

For the emissions, there are two different approaches. For the total and average costs, the emissions are calculated by using average emission factors per vehicle type and country (e.g. for road transport from the COPERT database). The emission factors applied are on the same level of differentiation as the transport data used. Total emissions are derived from the emission factors (tonne of pollutant per vkm) and the transport performance data (e.g. vkm), leading to a consistent set of emissions, that are in line with the emission databases (e.g. COPERT) and the official transport statistics from the EU (Eurostat). The resulting total emissions have been cross checked with the total emission database from the European Monitoring and Evaluation Program under auspices of the European Environmental Agency (EMEP/EEA). The overall results are well comparable for the main pollutants (NO_x, PM), although there are some differences (above all for NMVOC), as a result of different transport data and emission factors from the different sources (COPERT and Eurostat vs. EMEP/EEA). This difference cannot be avoided under the premise to take COPERT for emission data and Eurostat for transport data as the main data sources. This issue is, however, not relevant for any average and marginal cost factors, but only for the total costs. In the following section, an overview of the main data sources is presented.

The second type of input value are the cost factors per pollutants. The cost factors have been calculated in detail, based on the NEEDS approach, also taking into account the latest results from other studies (e.g. (UBA, 2018), (Rabl, et al., 2014), (OECD, 2014)). This has been done for the EU28 and a limited number of EU Member States in an on-going study by CE Delft. In the study at hand, this set has been extended to all member States and also for emissions from other sources. The following section briefly explains the methodology followed for calculating the cost factors per pollutant.

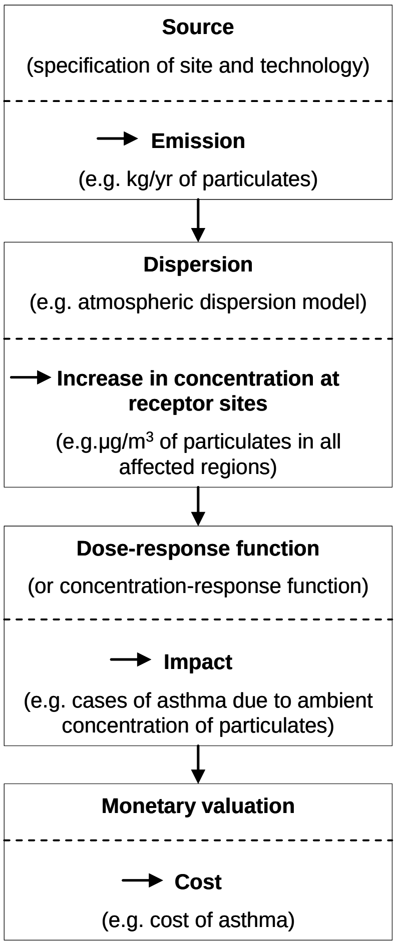
Methodology to derive damage cost factors

The method used for damage cost estimation is the same approach as followed in the Handbook Environmental Prices (CE Delft, 2018). This Handbook gives a damage cost estimation for over 2,500 pollutants. It is based on a combination of two models:
- Economic damage cost estimates, as performed in NEEDS (2008).
- Lifecycle Assessment, as performed in RECIPE (2013).

Both models have been adjusted to the most recent insights. For the present project especially the first model, the NEEDS model, is relevant. The core of the NEEDS-project is an Impact-Pathway model (EcoSense) that estimates the relationship between emissions and eventual impacts (see Figure 4). The Impact Pathway Approach (IPA) has been used in several international research projects initiated by the European Commission, starting with the original ExternE study implemented in the mid-1990s. We have adopted this model to reflect the most recent insights on the relationship between emissions and damage.

The starting point of the quantification of the cost factors is the NEEDS (2008) results, as they have been published in e.g. Desgaulles et al (2011) and further elaborated in Rabl et al. (2014). Within the NEEDS model, the impact-pathway approach is followed, in which an emission – through dispersion – results in an intake (immission) at receptor points.

Figure 4 - The Impact Pathway Approach for calculating air pollution costs



Source: CE Delft, 2010, based on NEEDS, 2008.

Since 2009 there has been no further development of NEEDS and neither of the rival model of CAFE-CBA (IIASA, 2014). It is also striking is that recent shadow price manuals for Ireland, Belgium and Germany (under development) are still based on the NEEDS methodology owing to its far greater transparency. However, one cannot simply take the NEEDS values and apply them to air pollution because the estimation results are over a decade old and many things have changed: background concentration levels, knowledge about impacts from pollution and the valuation framework. For that reason, adaptations to the NEEDS framework must be made. This is possible since we have the possession of a great deal of modelling outcomes from the NEEDS model so that we can make required changes to reflect more recent insights.

In total, to recalculate cost factors for air pollutants in the present study, five 'adjustments' (i.e. update calculations) were made to the NEEDS results.
These adjustments are broadly the same as in the Environmental Pricing Handbook (CE Delft, 2018), but they are now applied to the EU context. These five adjustments can be described as follows:

1. Concentration Response Functions (Step 3 in the figure above) have been adapted to the WHO (2013) study. The taken steps are described in Annex C.
2. The population size and population structure (age cohorts) is based on the most recent data from Eurostat.
3. The influence of the background concentration is estimated on the basis of the relationship between damage and emissions for various emission scenarios from NEEDS (2008). On this basis, by letting all other factors remain the same, we can estimate the impact of a change in emissions on the harmfulness of these emissions. This harmfulness is then the result of the change in the background concentration.
4. The valuation has been adjusted to the most recent insights with respect to valuation. For human health we refer to Annex A. The change in valuation of ecosystems and buildings, has been elaborated in more detail in Annex C.
5. Finally, a subdivision was made for both $PM_{2.5}$ and NO_2 to the population density (people living in cities or in rural areas have different damage from pollution). For $PM_{2.5}$ a further distinction was being made to transport emissions and other sources of emissions. For $PM_{2.5}$ and NO_x specific emission damages from electricity generation have also been calculated, as this information may be relevant to estimate the damage costs of electrical vehicles.

A detailed discussion of the adaptations is presented in Annex C.

4.3.2 Input values

Emissions

Table 13 gives an overview on the data sources used for calculating the emissions of air pollutants for the different transport modes. For all data, 2016 was taken as the reference year (transport data and emission factors), also for COPERT.

Table 13 – Data sources for the emissions of air pollutants for different transport modes

	Transport data	Emission factors (for total and average costs)	Emission factors (for selected cases)
Road Transport	EU Transport in Figures, Eurostat and COPERT v5	COPERT database v5 (country data)	COPERT database v5 (country data)
– *Passenger transport*	EU Transport in Figures, Eurostat and COPERT v5, TRACCS database	COPERT database v5 (country data)	COPERT database v5 (country data)
– *Freight transport*	Eurostat and COPERT v5, TRACCS database		
Rail Transport	Eurostat, EU Transport in Figures and TREMOVE	TREMOD (IFEU, 2017)	TREMOD (IFEU, 2017)
Air Transport	airports (survey), Eurostat	TREMOD (IFEU, 2017)	EEA, EMEP Guidebook; TREMOD
Inland Waterways	EU Transport in Figures and Eurostat	EcoTransitWorld and TREMOD (IFEU, 2017)	EcoTransitWorld and TREMOD (IFEU, 2017)
Maritime	ports (survey)	ISL Bremen	ISL Bremen

Cost factors

The following tables summarises the cost factors for air pollution used for calculating the health and other effects. Table 14 includes the cost factors per country for pollutants emitted in road, rail and inland waterway transport. Table 15 shows the cost factors for maritime transport.

Luxembourg has particularly high values compared to other countries. This is primarily due to the high value of the VOLY. Islands, such as Malta, Cyprus and Ireland, tend to have lower damage costs than countries in the mainland with comparable levels of income in purchasing power parities.[15] Bulgaria, Latvia and Estonia tend to have lower damage costs because of their lower income levels.

Table 14 – Air pollution costs: average damage cost in €/kg emission, national averages for transport emissions in 2016 (excl. maritime) (All effects: health effects, crop loss, biodiversity loss, material damage)

$€_{2016}$/kg	NH_3	NMVOC	SO_2	NO_x transport city°	NO_x transport rural°	$PM_{2.5}$ transport metropole°	$PM_{2.5}$ transport city°	$PM_{2.5}$ transport rural°	PM_{10} average*
Austria	27.8	2.3	16.2	41.4	24.3	466	151	87	30.9
Belgium	38.2	3.6	17.1	26.1	15.1	479	155	114	47.2
Bulgaria	5.6	0	4.2	10	5.9	191	61	30	5.4
Croatia	17.9	0.9	8	18.5	11.4	292	95	54	8.2
Cyprus	3.8	-0.4	7.8	8.1	4.5	n.a.**	71	17	20.1
Czech Republic	27.4	1.1	11.6	24.8	14.8	361	116	72	39.6
Denmark	14.0	1.5	9.6	16.2	9.6	470	151	59	15
Estonia	10.5	0.3	5.2	5.4	3.4	n.a.**	102	35	4.9
Finland	7.0	0.4	4.6	5.3	3.5	366	118	32	11.9
France	15.4	1.5	13.9	27.2	16.2	407	131	87	5.9
Germany	28.1	1.8	16.5	36.8	21.6	448	144	93	24.7

[15] The negative value for NMVOC emissions in Cyprus is related to the fact that NO_x is the main precursor of ozone in Cyprus and that emissions of NMVOC tend to lower the ozone concentrations.

€$_{2016}$/kg	NH_3	NMVOC	SO_2	NO_x transport city°	NO_x transport rural°	$PM_{2.5}$ transport metropole°	$PM_{2.5}$ transport city°	$PM_{2.5}$ transport rural°	PM_{10} average*
Greece	4.8	0.3	5.9	5.1	3.1	267	86	33	24.8
Hungary	18.9	0.8	9.9	26.8	15.8	317	102	59	8.5
Ireland	4.1	1.7	11.8	17.6	10.1	568	183	68	12.2
Italy	21.6	1.1	12.7	25.4	15.1	409	132	79	19
Latvia	8.7	0.4	4.8	7.2	4.4	251	81	28	17.2
Lithuania	7.9	0.6	6.4	12.1	7.1	300	98	38	27
Luxembourg	60.0	6.2	29.3	66.8	38.4	n.a.**	278	191	8
Malta	6.4	0.4	4.3	2.3	1.4	n.a.**	72	18	63.9
Netherlands	30.0	2.8	20.2	26.5	15.3	458	148	101	5.6
Poland	14.4	0.7	8.2	14.7	8.9	282	91	52	5.2
Portugal	4.3	0.5	4.1	2.8	1.7	292	94	39	47.3
Romania	9.4	0.5	7.3	19.4	11.2	272	88	42	16.1
Slovakia	24.4	0.7	10.1	24.8	14.7	328	105	59	12.3
Slovenia	23.8	1.2	9.2	22.3	13.7	n.a.**	93	52	12
Spain	6.4	0.7	6.8	8.5	5.1	348	112	46	10.2
Sweden	10.6	0.7	5.5	9.5	6	374	120	38	15.2
United Kingdom	17.6	1.4	10	13.6	7.9	380	122	65	16.2
EU28	**17.5**	**1.2**	10.9	21.3	12.6	**381**	**123**	**70**	**22.3**

Notes:

* PM_{10} cost factors can be used for the non-exhaust emission of particles PM, e.g. from brake and tyre abrasion.

** Metropole only applies to cities larger than 0.5 million inhabitants. Some countries do not have such cities hence these damage values are hence not being reported. This is the case for Slovenia, Malta, Luxembourg, Estonia and Cyprus.

° Rural area: outside cities; metropolitan area: cities/agglomeration with more than 0.5 million inhabitants.

Table 15 - Air pollution costs: average damage cost in €/kg emission, national averages for maritime emissions in 2016 (all effects: health effects, crop loss, biodiversity loss, material damage)

€$_{2016}$/kg	NH_3	NMVOC	SO_2	NO_x	$PM_{2.5}$	PM_{10}
Atlantic	0.0	0.4	3.5	3.8	7.2	4.1
Baltic	0.0	1.0	6.9	7.9	18.3	10.4
Black Sea	0.0	0.2	11.1	7.8	30.0	17.1
Mediterrenean	0.0	0.5	9.2	3.0	24.6	14.0
North Sea	0.0	2.3	10.5	10.7	34.4	19.7

4.3.3 Output values

The following tables show the resulting cost factors (output values) for the air pollution costs per vehicle type. The tables include the total costs as well as the average costs per vkm and per pkm or tkm.

Table 16 - Total and average air pollution costs for land-based modes for the EU28

Transport mode	Total costs EU28	Average costs	
Passenger transport	**Billion €**	**€-cent/pkm**	**€-cent/vkm**
Passenger car	33.36	0.71	1.14
Passenger car - petrol	8.58	0.33	0.53
Passenger car - diesel	24.79	1.18	1.90
Motorcycle	1.84	1.12	1.17
Bus	1.35	0.76	14.19
Coach	2.67	0.73	14.34
Total passenger road	**39.23**		
High speed passenger train	0.002	0.002	0.66
Passenger train electric	0.03*	0.01	1.14
Passenger train diesel	0.52	0.80	47.0
Total passenger rail	**0.55**		
Total passenger transport	**39.78**		
Freight transport	**Billion €**	**€-cent/tkm**	**€-cent/vkm**
LCV	15.49	4.68	3.24
LCV - petrol	0.33	1.72	1.17
LCV - diesel	15.16	4.86	3.37
HGV	13.93	0.76	9.38
Total freight road	**29.42**		
Freight train electric	0.01	0.004	2.14
Freight train diesel	0.66	0.68	305.39
Total freight rail	**0.67**		
Inland Vessel	1.93	1.29	1,869
Total freight transport	**32.02**		
Total road, rail, inland waterway	**71.80**		

* Total costs without highspeed passenger trains (average costs for passenger train electric: incl. high speed trains).

Table 17 - Total and average air pollution costs for aviation for 33 selected EU airports

Type of flight	Billion €	€-cent/pkm	€-cent/pax*
Short haul (< 1,500 km)	0.27	0.30	163
Medium haul (1,500-5,000 km)	0.38	0.13	231
Long haul (> 5,000 km)	0.36	0.06	444
Total	1.01	0.10	246

* Costs per pax are including the complete flight (not only the half-way principle).

Table 18 presents rough estimates for the average external air pollution costs of maritime transport. These data are only available for freight. The average cost have been based on the cost for reference cases presented in Section 4.4 and data on the number of port calls for the selected ports from Eurostat. The total air pollution cost has been based on the average cost and the number of tkms provided by DG MOVE[16]. The available data does not allow an estimate of costs at the individual port level.

[16] Some assumptions had to be made for calculating maritime transport performance. The Eurostat transport volumes (i.e. tonnes) and distance matrices have been used for this purpose. By assumption, 50% of the

Table 18 - Rough estimates for total and average external air pollution costs for maritime transport for 34 selected EU ports

Transport mode	Total costs (bn €)	Average costs (€-cent/tkm)
Freight ship	29	0.4

4.4 Marginal air pollution costs for selected cases

For air pollution costs, the marginal costs are virtually the same as the average costs. This is mainly because the dose-response relationships between the immissions of air pollutants and health effects (or other damages) are nearly linear according to epidemiological studies. Therefore, the present chapter also covers average air pollution costs. The methodology used is the same as for the total and average costs (see Figure 3 above).

The costs for road vehicles are presented for all differentiations provided by COPERT, e.g. different fuel types, engines or vehicle sizes, emission classes and regional areas. It needs to be emphasized that for a modern car (after Euro 1), engine size is not a cost driver for the air pollution costs of cars. Therefore, these costs are identical for the various engine size classes. Any differences are the result of rounding numbers from the COPERT data.

Table 19 on marginal air pollution costs for road transport shows the costs per pkm or tkm (except for LCV, where costs per vkm are presented due to the fact that LCV have characteristics of freight and passenger transport). The costs per vkm for the different vehicle categories of road transport are available in the background Excel file.

Table 19 - Marginal air pollution costs road transport for selected cases

Vehicle	Fuel type	Size	Emission class	Metropolitan area			Urban area		Rural area	
				Motorway	Urban road	Other road	Motorway	Urban road	Motorway	Rural road
Passenger transport (€-cent per pkm)										
Passenger Cars	Petrol	Mini < 0.8 l	Euro 4	0.05	0.12	0.06	0.04	0.10	0.02	0.03
			Euro 5	0.05	0.08	0.06	0.03	0.06	0.02	0.02
			Euro 6	0.05	0.09	0.06	0.03	0.06	0.02	0.02
		Small 0.8-1.4 l	Euro 0	2.91	2.69	2.99	2.88	2.63	1.76	1.82
			Euro 1	0.82	0.55	0.48	0.79	0.50	0.50	0.29
			Euro 2	0.36	0.37	0.30	0.33	0.32	0.22	0.18
			Euro 3	0.17	0.19	0.15	0.15	0.17	0.11	0.10
			Euro 4	0.12	0.17	0.11	0.10	0.15	0.08	0.07
			Euro 5	0.12	0.13	0.10	0.09	0.11	0.08	0.07
			Euro 6	0.12	0.14	0.10	0.09	0.11	0.08	0.07
		Medium 1.4-2.0 l	Euro 0	4.53	3.04	3.80	4.50	2.99	2.73	2.30
			Euro 1	0.86	0.55	0.48	0.83	0.50	0.52	0.29
			Euro 2	0.36	0.37	0.30	0.33	0.32	0.22	0.18

calculated transport performance is allocated to the origin country and 50% to the destination country between EU Countries and EFTA and candidate countries. For the international extra-EU activity, where the corresponding partner is outside EU28 and is not an EFTA or candidate country, 100% of transport performance is allocated to the declaring EU MS country. These assumptions are used only for this study purposes and shall be considered as estimates and not as official data.

Vehicle	Fuel type	Size	Emission class	Metropolitan area			Urban area		Rural area	
				Motorway	Urban road	Other road	Motorway	Urban road	Motorway	Rural road
			Euro 3	0.17	0.19	0.15	0.15	0.17	0.12	0.10
			Euro 4	0.12	0.17	0.11	0.10	0.15	0.08	0.07
			Euro 5	0.12	0.13	0.10	0.09	0.11	0.08	0.07
			Euro 6	0.12	0.14	0.10	0.09	0.11	0.08	0.07
		Large-SUV-Executive > 2.0 l	Euro 0	8.16	3.77	5.65	8.12	3.71	4.87	3.39
			Euro 1	0.88	0.55	0.48	0.85	0.50	0.53	0.29
			Euro 2	0.36	0.37	0.30	0.33	0.32	0.22	0.18
			Euro 3	0.17	0.19	0.15	0.15	0.17	0.12	0.10
			Euro 4	0.12	0.17	0.11	0.10	0.15	0.08	0.07
			Euro 5	0.12	0.13	0.10	0.09	0.11	0.08	0.07
			Euro 6	0.12	0.14	0.10	0.09	0.11	0.08	0.07
	Diesel	Mini < 0.8 l	Euro 4	1.65	1.70	1.21	1.20	1.17	0.73	0.49
			Euro 5	0.92	1.04	0.74	0.90	0.99	0.56	0.44
			Euro 6	0.76	0.86	0.61	0.75	0.82	0.47	0.37
		Small 0.8-1.4 l	Euro 0	5.81	6.83	3.84	2.47	2.79	1.45	0.99
			Euro 1	4.17	2.56	2.28	2.05	1.50	1.22	0.77
			Euro 2	2.49	2.39	1.74	1.54	1.51	0.93	0.66
			Euro 3	2.45	1.90	1.66	1.59	1.37	0.96	0.71
			Euro 4	1.65	1.70	1.21	1.20	1.17	0.73	0.49
			Euro 5	0.92	1.04	0.74	0.90	0.99	0.56	0.44
			Euro 6	0.76	0.86	0.61	0.75	0.82	0.47	0.37
		Medium 1.4-2.0 l	Euro 0	6.11	7.05	4.03	2.73	3.01	1.61	1.10
			Euro 1	4.21	2.56	2.29	2.06	1.50	1.22	0.77
			Euro 2	2.51	2.39	1.75	1.55	1.51	0.93	0.67
			Euro 3	2.47	1.90	1.66	1.60	1.37	0.97	0.71
			Euro 4	1.67	1.70	1.21	1.21	1.17	0.74	0.49
			Euro 5	0.93	1.04	0.74	0.90	0.99	0.56	0.44
			Euro 6	0.77	0.86	0.61	0.75	0.82	0.47	0.37
		Large-SUV-Executive > 2.0 l	Euro 0	6.41	7.27	4.22	3.00	3.23	1.77	1.22
			Euro 1	4.25	2.56	2.31	2.08	1.50	1.23	0.77
			Euro 2	2.53	2.40	1.75	1.56	1.51	0.94	0.67
			Euro 3	2.49	1.90	1.67	1.62	1.37	0.97	0.71
			Euro 4	1.68	1.70	1.21	1.22	1.17	0.74	0.49
			Euro 5	0.93	1.04	0.74	0.91	0.99	0.56	0.44
			Euro 6	0.77	0.86	0.61	0.76	0.82	0.47	0.37
	Petrol Hybrid (PHEV)	Mini	n.a.	0.09	0.06	0.07	0.09	0.06	0.08	0.06
		Small	n.a.	0.09	0.06	0.07	0.09	0.06	0.08	0.06
		Large-SUV-Executive	n.a.	0.09	0.06	0.07	0.09	0.06	0.08	0.06
	LPG Bifuel	Small	Euro 1	0.55	0.65	0.47	0.52	0.60	0.34	0.28
			Euro 2	0.27	0.31	0.23	0.24	0.26	0.17	0.14
			Euro 3	0.17	0.19	0.15	0.15	0.17	0.12	0.10
			Euro 4	0.12	0.17	0.11	0.10	0.15	0.08	0.07
			Euro 5	0.11	0.15	0.10	0.09	0.13	0.08	0.07
			Euro 6	0.11	0.15	0.10	0.09	0.13	0.08	0.07
	CNG Bifuel	Small	Euro 4	0.12	0.17	0.11	0.10	0.15	0.09	0.08
			Euro 5	0.11	0.14	0.10	0.09	0.12	0.08	0.07
			Euro 6	0.11	0.14	0.10	0.09	0.12	0.08	0.07

Vehicle	Fuel type	Size	Emission class	Metropolitan area			Urban area		Rural area	
				Motorway	Urban road	Other road	Motorway	Urban road	Motorway	Rural road
	Electric (BEV)	n.a.	n.a.	0.06	0.05	0.05	0.06	0.05	0.06	0.05
Moped	Petrol	2-stroke < 50 cm³	Euro 0	7.46	7.45	7.45	3.13	3.13	2.20	2.19
			Euro 1	2.41	2.40	2.40	1.30	1.29	0.92	0.92
			Euro 2	1.61	1.60	1.60	0.97	0.96	0.70	0.69
			Euro 3	1.20	1.20	1.20	0.76	0.76	0.53	0.53
		4-stroke < 50 cm³	Euro 0	7.46	7.45	7.45	3.13	3.13	2.20	2.19
			Euro 1	2.01	2.00	2.00	1.02	1.02	0.64	0.63
			Euro 2	0.71	0.71	0.70	0.54	0.53	0.36	0.35
			Euro 3	0.57	0.57	0.57	0.47	0.47	0.31	0.31
Motorcycle	Petrol	2-stroke ≥ 50 cm³	Euro 0	8.49	8.44	8.13	3.57	3.53	2.53	2.18
			Euro 1	3.52	3.34	3.29	1.56	1.38	1.10	0.88
			Euro 2	1.88	1.74	1.73	0.89	0.76	0.63	0.50
			Euro 3	0.69	0.61	0.61	0.40	0.31	0.31	0.23
		4-stroke < 250 cm³	Euro 0	2.00	1.45	1.67	1.51	0.96	0.93	0.73
			Euro 1	2.08	1.45	1.73	1.59	0.96	0.98	0.76
			Euro 2	1.49	0.72	1.00	1.36	0.60	0.84	0.54
			Euro 3	1.27	0.67	0.86	1.15	0.55	0.70	0.45
		4-stroke 250-750 cm³	Euro 0	2.24	1.55	1.69	1.75	1.06	1.08	0.77
			Euro 1	2.13	1.39	1.61	1.63	0.90	1.00	0.70
			Euro 2	0.90	0.42	0.51	0.78	0.29	0.50	0.25
			Euro 3	0.57	0.32	0.36	0.45	0.19	0.29	0.16
		4-stroke > 750 cm³	Euro 0	1.95	1.32	1.28	1.46	0.83	0.94	0.53
			Euro 1	1.93	1.18	1.31	1.44	0.68	0.89	0.51
			Euro 2	1.54	0.47	0.64	1.41	0.34	0.87	0.32
			Euro 3	0.89	0.34	0.43	0.77	0.22	0.48	0.20
	Electric		n.a.	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Urban buses	Diesel	Midi <=15 t	Euro 0	2.28	4.75	2.46	1.51	2.79	0.89	0.95
			Euro I	1.26	2.33	1.37	0.92	1.69	0.55	0.60
			Euro II	1.11	1.96	1.20	0.91	1.65	0.54	0.60
			Euro III	0.83	1.87	0.93	0.65	1.55	0.39	0.45
			Euro IV	0.47	0.95	0.54	0.43	0.87	0.26	0.30
			Euro V	0.39	1.15	0.44	0.33	1.06	0.20	0.24
			Euro VI	0.03	0.13	0.05	0.03	0.13	0.02	0.03
	Diesel	Standard 15-18 t	Euro 0	2.11	4.40	2.35	1.59	3.00	0.94	1.04
			Euro I	1.30	2.53	1.43	0.96	1.80	0.57	0.63
			Euro II	1.16	2.09	1.26	0.95	1.75	0.56	0.62
			Euro III	0.86	1.93	0.98	0.69	1.60	0.41	0.48
			Euro IV	0.50	1.00	0.57	0.46	0.92	0.28	0.32
			Euro V	0.35	1.16	0.40	0.30	1.07	0.18	0.21
			Euro VI	0.03	0.12	0.04	0.03	0.11	0.02	0.03
	Diesel	Articulated > 18 t	Euro 0	2.19	4.54	2.51	1.64	3.12	0.97	1.10
			Euro I	1.37	2.64	1.52	1.00	1.88	0.59	0.67
			Euro II	1.19	2.18	1.31	0.96	1.80	0.57	0.64
			Euro III	0.90	1.98	1.02	0.73	1.63	0.43	0.50
			Euro IV	0.51	1.07	0.62	0.47	0.99	0.28	0.34
			Euro V	0.30	1.01	0.34	0.25	0.92	0.15	0.17
			Euro VI	0.03	0.09	0.04	0.03	0.08	0.02	0.03

Vehicle	Fuel type	Size	Emission class	Metropolitan area			Urban area		Rural area	
				Motorway	Urban road	Other road	Motorway	Urban road	Motorway	Rural road
	CNG	CNG buses	Euro I	2.13	2.13	2.13	2.10	2.10	1.24	1.24
			Euro II	1.92	1.92	1.92	1.90	1.90	1.13	1.13
			Euro III	1.28	1.28	1.28	1.27	1.27	0.75	0.75
			EEV*	0.26	0.53	0.30	0.25	0.52	0.15	0.17
	Bio-diesel	Biodiesel buses	Euro 0	2.10	4.36	2.34	1.58	2.97	0.93	1.02
			Euro I	1.29	2.49	1.42	0.95	1.76	0.56	0.62
			Euro II	1.15	2.05	1.24	0.94	1.71	0.55	0.61
			Euro III	0.85	1.90	0.97	0.68	1.56	0.40	0.46
			Euro IV	0.49	0.96	0.55	0.45	0.88	0.26	0.30
			Euro V	0.34	1.12	0.39	0.29	1.03	0.17	0.20
			Euro VI	0.02	0.08	0.03	0.01	0.07	0.01	0.01
	Electric	Small	n.a.	0.01	0.05	0.02	0.01	0.05	0.01	0.02
		Medium	n.a.	0.01	0.04	0.02	0.01	0.04	0.01	0.02
		Large	n.a.	0.01	0.03	0.01	0.01	0.03	0.01	0.01
Coaches	Diesel	Standard <=18 t	Euro 0	1.77	3.99	2.02	1.35	2.77	0.80	0.88
			Euro I	1.34	3.19	1.56	1.02	2.21	0.60	0.68
			Euro II	1.24	2.64	1.39	1.05	2.21	0.62	0.69
			Euro III	1.01	2.67	1.19	0.83	2.12	0.50	0.57
			Euro IV	0.61	1.34	0.68	0.56	1.23	0.34	0.38
			Euro V	0.37	1.86	0.59	0.32	1.71	0.19	0.31
			Euro VI	0.04	0.21	0.07	0.03	0.19	0.02	0.04
	Diesel	Articulated > 18 t	Euro 0	1.42	3.22	1.62	1.07	2.26	0.63	0.71
			Euro I	1.04	2.51	1.23	0.79	1.77	0.47	0.54
			Euro II	0.95	2.05	1.08	0.79	1.72	0.47	0.54
			Euro III	0.73	1.97	0.88	0.60	1.56	0.36	0.42
			Euro IV	0.44	1.00	0.50	0.41	0.91	0.24	0.28
			Euro V	0.26	1.35	0.41	0.21	1.25	0.13	0.22
			Euro VI	0.02	0.14	0.04	0.02	0.13	0.01	0.03
Light commercial vehicle (€-cent per vkm)										
Light Commercial Vehicle	Petrol		Euro 0	8.31	5.84	7.05	8.26	5.75	4.96	4.20
			Euro 1	1.32	1.20	1.02	1.27	1.12	0.80	0.61
			Euro 2	0.56	0.54	0.44	0.51	0.45	0.34	0.26
			Euro 3	0.39	0.33	0.29	0.36	0.30	0.25	0.19
			Euro 4	0.26	0.22	0.19	0.23	0.19	0.18	0.13
			Euro 5	0.27	0.16	0.18	0.17	0.13	0.14	0.10
			Euro 6	0.27	0.16	0.18	0.17	0.13	0.14	0.10
	Diesel		Euro 1	9.18	6.22	4.93	4.91	3.94	2.91	1.82
			Euro 2	9.18	6.22	4.93	4.91	3.94	2.91	1.82
			Euro 3	6.65	4.66	3.68	3.79	3.13	2.26	1.45
			Euro 4	4.19	3.13	2.46	2.69	2.34	1.62	1.09
			Euro 5	3.98	2.69	2.58	3.96	2.65	2.38	1.54
			Euro 6	3.24	2.19	2.10	3.22	2.16	1.94	1.26
	Electric		n.a.	0.10	0.08	0.07	0.10	0.08	0.10	0.07
Freight transport (€-cent per tkm)										
HGV	Diesel	Rigid <=7,5 t	Euro 0	22.05	30.29	21.88	15.44	18.35	9.19	8.71
			Euro I	13.38	15.86	12.34	10.57	11.17	6.32	5.66
			Euro II	12.35	12.87	10.96	10.35	10.78	6.20	5.58
			Euro III	8.79	11.65	8.41	7.54	9.18	4.54	4.22

Vehicle	Fuel type	Size	Emission class	Metropolitan area			Urban area		Rural area	
				Motorway	Urban road	Other road	Motorway	Urban road	Motorway	Rural road
			Euro IV	5.74	6.28	5.18	5.28	5.77	3.21	2.93
			Euro V	2.84	7.85	2.96	2.37	7.20	1.49	1.59
			Euro VI	0.32	1.55	0.47	0.28	1.48	0.26	0.36
		Rigid 7,5-12 t	Euro 0	11.55	16.51	11.64	9.07	11.58	5.39	5.26
			Euro I	7.08	10.11	7.04	5.49	7.06	3.27	3.18
			Euro II	6.72	8.12	6.26	5.51	6.77	3.29	3.14
			Euro III	4.75	7.23	4.96	3.99	5.68	2.39	2.46
			Euro IV	2.97	3.81	2.99	2.73	3.49	1.65	1.67
			Euro V	1.55	4.93	1.77	1.28	4.53	0.79	0.93
			Euro VI	0.20	0.70	0.26	0.18	0.66	0.14	0.18
		Rigid 12-14 t	Euro 0	6.65	9.82	6.72	5.10	6.98	3.03	3.02
			Euro I	4.07	6.05	4.11	3.10	4.28	1.84	1.84
			Euro II	3.83	4.96	3.65	3.10	4.14	1.85	1.82
			Euro III	2.78	4.46	2.90	2.30	3.57	1.38	1.44
			Euro IV	1.67	2.39	1.74	1.54	2.20	0.93	0.98
			Euro V	0.89	2.89	1.06	0.74	2.66	0.45	0.56
			Euro VI	0.11	0.38	0.14	0.10	0.35	0.08	0.10
		Rigid 14-20 t	Euro 0	7.49	12.30	7.96	5.66	8.58	3.36	3.50
			Euro I	4.46	7.54	4.79	3.36	5.25	1.99	2.10
			Euro II	4.24	6.02	4.17	3.43	5.04	2.04	2.08
			Euro III	3.11	5.58	3.45	2.56	4.40	1.53	1.68
			Euro IV	1.88	2.86	2.00	1.74	2.63	1.04	1.12
			Euro V	1.02	3.91	1.62	0.85	3.61	0.52	0.87
			Euro VI	0.13	0.51	0.18	0.11	0.48	0.08	0.12
		Rigid 20-26 t	Euro 0	3.69	6.21	3.99	2.74	4.43	1.62	1.75
			Euro I	2.65	4.70	2.88	1.96	3.25	1.16	1.25
			Euro II	2.48	3.74	2.51	1.98	3.10	1.18	1.24
			Euro III	1.89	3.35	2.06	1.56	2.64	0.93	1.00
			Euro IV	1.13	1.75	1.20	1.05	1.60	0.63	0.67
			Euro V	0.58	2.17	0.85	0.48	1.98	0.29	0.45
			Euro VI	0.06	0.26	0.09	0.05	0.24	0.04	0.06
		Rigid 26-28 t	Euro 0	2.74	4.59	2.98	2.03	3.26	1.19	1.29
			Euro I	1.96	3.43	2.15	1.44	2.38	0.85	0.92
			Euro II	1.84	2.78	1.87	1.46	2.30	0.87	0.92
			Euro III	1.38	2.45	1.52	1.13	1.93	0.67	0.73
			Euro IV	0.82	1.29	0.87	0.76	1.18	0.46	0.48
			Euro V	0.39	1.58	0.61	0.32	1.45	0.19	0.32
			Euro VI	0.05	0.18	0.07	0.04	0.17	0.03	0.04
		Rigid 28-32 t	Euro 0	2.55	4.14	2.75	1.89	2.94	1.11	1.20
			Euro I	1.86	3.14	2.02	1.37	2.21	0.81	0.88
			Euro II	1.74	2.54	1.76	1.37	2.10	0.81	0.86
			Euro III	1.28	2.21	1.40	1.05	1.75	0.63	0.68
			Euro IV	0.76	1.19	0.82	0.71	1.09	0.42	0.45
			Euro V	0.33	1.34	0.49	0.27	1.23	0.16	0.25
			Euro VI	0.05	0.14	0.06	0.04	0.13	0.03	0.04
		Rigid > 32 t	Euro 0	2.21	3.77	2.40	1.63	2.69	0.96	1.04
			Euro I	1.62	2.89	1.76	1.18	2.01	0.70	0.76
			Euro II	1.51	2.32	1.54	1.19	1.91	0.71	0.75

Vehicle	Fuel type	Size	Emission class	Metropolitan area			Urban area		Rural area	
				Motorway	Urban road	Other road	Motorway	Urban road	Motorway	Rural road
			Euro III	1.14	2.02	1.25	0.93	1.60	0.55	0.61
			Euro IV	0.68	1.08	0.73	0.63	0.99	0.38	0.40
			Euro V	0.32	1.20	0.45	0.26	1.10	0.16	0.23
			Euro VI	0.03	0.13	0.05	0.03	0.12	0.02	0.03
		Articulated 14-20 t	Euro 0	3.99	6.74	4.33	3.00	4.74	1.77	1.89
			Euro I	2.44	4.14	2.60	1.80	2.88	1.06	1.12
			Euro II	2.27	3.33	2.27	1.81	2.77	1.07	1.11
			Euro III	1.70	3.01	1.85	1.38	2.38	0.82	0.89
			Euro IV	1.00	1.55	1.07	0.92	1.41	0.54	0.58
			Euro V	0.51	1.95	0.76	0.42	1.79	0.25	0.39
			Euro VI	0.05	0.17	0.06	0.04	0.15	0.02	0.03
		Articulated 20-28 t	Euro 0	3.54	6.07	3.87	2.60	4.36	1.54	1.70
			Euro I	2.58	4.56	2.84	1.88	3.23	1.11	1.23
			Euro II	2.37	3.68	2.43	1.86	3.05	1.10	1.19
			Euro III	1.77	3.25	1.97	1.42	2.58	0.85	0.95
			Euro IV	1.03	1.73	1.14	0.95	1.59	0.57	0.63
			Euro V	0.52	2.01	0.76	0.43	1.84	0.26	0.40
			Euro VI	0.07	0.22	0.08	0.06	0.20	0.04	0.05
		Articulated 28-34 t	Euro 0	2.21	3.84	2.42	1.62	2.76	0.96	1.06
			Euro I	1.62	2.89	1.77	1.17	2.03	0.69	0.77
			Euro II	1.47	2.31	1.51	1.14	1.91	0.68	0.74
			Euro III	1.09	2.01	1.22	0.88	1.60	0.52	0.59
			Euro IV	0.63	1.09	0.71	0.58	1.00	0.35	0.39
			Euro V	0.30	1.18	0.44	0.25	1.07	0.15	0.23
			Euro VI	0.04	0.12	0.05	0.04	0.11	0.03	0.03
		Articulated 34-40 t	Euro 0	2.18	3.92	2.41	1.59	2.81	0.94	1.05
			Euro I	1.59	2.98	1.77	1.15	2.07	0.68	0.76
			Euro II	1.47	2.39	1.53	1.15	1.96	0.68	0.74
			Euro III	1.11	2.07	1.24	0.90	1.64	0.54	0.60
			Euro IV	0.65	1.10	0.72	0.60	1.01	0.36	0.40
			Euro V	0.32	1.20	0.45	0.26	1.08	0.16	0.23
			Euro VI	0.03	0.12	0.04	0.03	0.11	0.02	0.03
		Articulated 40-50 t	Euro 0	2.07	3.74	2.30	1.51	2.69	0.89	1.01
			Euro I	1.53	2.84	1.69	1.09	1.97	0.65	0.72
			Euro II	1.40	2.27	1.46	1.09	1.86	0.64	0.71
			Euro III	1.04	1.93	1.17	0.85	1.54	0.50	0.57
			Euro IV	0.62	1.05	0.68	0.57	0.97	0.34	0.38
			Euro V	0.28	1.04	0.39	0.23	0.94	0.14	0.20
			Euro VI	0.03	0.10	0.04	0.02	0.09	0.02	0.02
		Articulated 50-60 t	Euro 0	2.16	3.94	2.41	1.58	2.86	0.93	1.06
			Euro I	1.59	2.97	1.77	1.13	2.07	0.67	0.76
			Euro II	1.45	2.39	1.52	1.12	1.95	0.66	0.73
			Euro III	1.09	2.04	1.21	0.88	1.62	0.52	0.59
			Euro IV	0.60	1.09	0.71	0.55	1.01	0.33	0.39
			Euro V	0.27	1.00	0.38	0.22	0.89	0.13	0.19
			Euro VI	0.03	0.10	0.04	0.02	0.09	0.02	0.02
	LNG	Articulated 32 t+	n.a.	0.03	0.09	0.03	0.02	0.08	0.02	0.02

* EEV: Enhanced environmentally friendly vehicle. European emission standard for the definition of a 'clean vehicle' > 3.5 t. Emission level between Euro V and Euro VI.

Table 20 - Marginal air pollution costs rail transport for selected cases

Train type	Traction	Emission class	Metropolitan area	Urban area	Rural area
Passenger transport (€-cent per pkm)					
High speed train [1]	Electric	n.a.	0.002	0.002	0.002
Intercity train	Electric	n.a.	0.01	0.01	0.01
	Diesel	Equipped with EGR/SCR	0.47	0.38	0.23
		Not Equipped with EGR/SC	0.70	0.67	0.40
Regional train	Electric	n.a.	0.02	0.02	0.02
	Diesel	Equipped with EGR/SCR	1.52	1.17	0.71
		Not Equipped with EGR/SCR	2.10	1.99	1.20
Freight transport (€-cent per tkm)					
Short container freight train (420 metres)	Electric	n.a.	0.004	0.004	0.004
	Diesel	Equipped with EGR/SCR	0.356	0.309	0.184
		Not Equipped with EGR/SCR	0.781	0.638	0.377
Short bulk freight train (300 metres)	Electric	n.a.	0.004	0.004	0.004
	Diesel	Equipped with EGR/SCR	0.238	0.207	0.123
		Not Equipped with EGR/SCR	0.521	0.426	0.252
Long container freight train (620 metres)	Electric	n.a.	0.004	0.004	0.004
	Diesel	Equipped with EGR/SCR	0.128	0.111	0.067
		Not Equipped with EGR/SCR	0.280	0.229	0.136
Long bulk freight train (440 metres)	Electric	n.a.	0.004	0.004	0.004
	Diesel	Equipped with EGR/SCR	0.113	0.098	0.059
		Not Equipped with EGR/SCR	0.245	0.200	0.119

1) There is no literature on the differences between high-speed trains and 'normal' intercity trains in terms of PM non-exhaust emissions. Most of the PM-emissions are caused by braking. Newer brake pads cause much less PM non-exhaust emissions than old cast iron brake pads. High-speed trains have probably newer brake pads. Tough high-speed trains are heavier and drive faster, they brake less because of the less winding tracks. It is not known how PM non-exhaust emissions from high-speed trains behave compared to Intercity-trains. That's why these are here equated with 'normal' Intercity trains.

Table 21 – Marginal air pollution costs IWT for selected cases

Vessel type	Type of cargo	Emission class	Urban area		Rural area	
			€-cent/tkm	€-cent/vkm	€-cent/tkm	€-cent/vkm
CEMT II (350 t)	Bulk	CCNR 0	3.36	1,074	1.98	631
		CCNR 1	2.82	899	1.66	529
		CCNR 2	1.82	580	1.07	342
		Average	3.25	1,039	1.91	610
	Container	CCNR 0	2.14	1,074	1.26	631
		CCNR 1	1.79	899	1.05	529
		CCNR 2	1.15	580	0.68	342
		Average	2.07	1,039	1.21	610
CEMT IV (600 t)	Bulk	CCNR 0	2.00	1,594	1.17	936
		CCNR 1	1.67	1,335	0.98	786
		CCNR 2	1.08	861	0.64	507
		Average	1.84	1,470	1.08	864
CEMT Va (1,500 t)	Bulk	CCNR 0	1.82	2,912	1.07	1,711
		CCNR 1	1.53	2,439	0.90	1,435
		CCNR 2	0.99	1,573	0.58	926
		Average	1.53	2,449	0.90	1,440
	Container	CCNR 0	2.06	2,912	1.21	1,711
		CCNR 1	1.73	2,439	1.02	1,435
		CCNR 2	1.12	1,573	0.66	926
		Average	1.74	2,449	1.02	1,440
Pushed convoy (11,000 t)	Bulk	CCNR 0	1.48	7,799	0.87	4,582
		CCNR 1	1.24	6,531	0.73	3,844
		CCNR 2	0.80	4,213	0.47	2,480
		Average	0.89	4,714	0.53	2,775
	Container	CCNR 0	1.10	7,799	0.65	4,582
		CCNR 1	0.92	6,531	0.54	3,844
		CCNR 2	0.60	4,213	0.35	2,480
		Average	0.67	4,714	0.39	2,775

Table 22 - Marginal air pollution costs maritime transport for selected cases

Vessel type	Distance at sea (km)	Tier	€ per port call	€-cent per pkm or tkm	€ per vessel-km
Passenger transport					
RoPax Ferry (25,500 gt)	100	Tier 0	19,232	36.42	192
		Tier 1	16,731	31.69	167
		Tier 2	15,198	28.78	152
	500	Tier 0	64,986	24.62	130
		Tier 1	58,691	22.23	117
		Tier 2	54,832	20.77	110
Freight transport					
Small container vessel (28,500 gt)	500	Tier 0	137,036	1.14	274
		Tier 1	119,408	1.00	239
		Tier 2	108,604	0.91	217
	3,000	Tier 0	370,353	0.51	123
		Tier 1	365,811	0.51	122
		Tier 2	206,856	0.29	69
Large container vessel (143,000 gt)	500	Tier 0	259,014	0.45	518
		Tier 1	232,364	0.40	465
		Tier 2	216,030	0.38	432
	3,000	Tier 0	868,167	0.25	289
		Tier 1	858,333	0.25	286
		Tier 2	514,162	0.15	171
	15,000	Tier 0	3,041,358	0.18	203
		Tier 1	2,695,909	0.16	180
		Tier 2	1,751,684	0.10	117
Small bulk vessel (18,000 gt)	500	Tier 0	46,763	0.62	94
		Tier 1	41,614	0.55	83
		Tier 2	38,459	0.51	77
	3,000	Tier 0	149,567	0.33	50
		Tier 1	147,827	0.33	49
		Tier 2	86,922	0.19	29
Large bulk vessel (105,000 gt)	500	Tier 0	115,019	0.22	230
		Tier 1	102,473	0.20	205
		Tier 2	94,783	0.18	190
	3,000	Tier 0	358,106	0.12	119
		Tier 1	354,077	0.11	118
		Tier 2	213,057	0.07	71
	15,000	Tier 0	1,232,817	0.08	82
		Tier 1	1,095,755	0.07	73
		Tier 2	721,118	0.05	48

Table 23 – Marginal air pollution costs aviation for selected cases

Type of flight	Distance [km]	Emission class	Example of aircraft type	€ per LTO*	€-cent per pkm*	€ per pax*
Short haul	500	Low	Bombardier CRJ900	101	0.28	1.42
	500	High	Embraer 170	137	0.30	1.52
Medium haul	1,500	Low	Airbus 320	165	0.07	1.11
	1,500	High	Boeing 737	185	0.11	1.58
	3,000	Low	Airbus 320	219	0.05	1.47
	3,000	High	Boeing 737	245	0.07	2.09
Long haul	5,000	Low	Airbus 340	502	0.03	1.70
	5,000	High	Boeing 777	833	0.04	1.92
	15,000	Low	Airbus 340	711	0.02	2.41
	15,000	High	Boeing 777	1.179	0.02	2.72

* For the cost factors for air pollution costs the emissions during the LTO cycle are mainly relevant, as the cruise emissions almost lead to no damage costs.

The marginal costs of aviation for selected cases and aircrafts cannot be directly compared with the average costs: The marginal costs refer to very specific aircraft types, distances and loading factors that do not match the average. E.g. for short haul flights, the average number of passenger per flight is substantially higher than for the selected cases (since many short haul flights are done by larger aircraft). Additionally, the average distances are different than the one use in the selected cases.

4.5 Robustness of results

Generally, the air pollution costs have had a long history of research and are therefore investigated and analysed in a very detailed way. For example, the scientific knowledge on dose-response relationships for diseases induced by air pollutants is very profound. Hence, compared to other cost categories, the cost factors for air pollution costs can be regarded as robust.

For the present Handbook, the most important parameters for the robustness of the results are the quality of the emission factors and the cost factors for the different air pollutants (damage costs per air pollutant), which are listed hereafter.

Emission factors

— For road transport, the COPERT database is the main input, which is a widely used source and considered a reliable data source. However, it is not clear to what extent the emissions data used fully reflect the latest findings on real world emissions, e.g. due to degradation and/or failure of particulate filters and catalysts in older vehicles.
— For other modes, the emission factors are from different sources, mainly from TREMOD (from the German Umweltbundesamt) and EcoTransitWorld. Both data bases are of high quality. However, the differentiated emission factors for different emission classes for rail, inland waterways and maritime have a higher uncertainty.

Damage cost factors

- The estimation of damage cost factors is based on the NEEDS approach and includes a broad update of the NEEDS data. It includes on the one hand up-to-date data on concentration response functions and the valuation of damage, and on the other hand differentiated data per country on population size and structure (density) and background concentration. Overall, we regard the quality of the damage cost factors per country and air pollutant as high, although an update of the NEEDS study is recommended.
- The cost factors reflect the cost for which the causal relation between emissions and health impacts has been proven. However, for some potential health problems, a causal relation is suspected, but not scientifically proven (yet). When it turns out that these relations can be proven by ongoing research, this would result in higher cost estimates.
- An important factor for uncertainties is the valuation of immaterial damage (i.e. value of value of life year lost VOLY). The value used is based on a meta-analysis, however, due to results from various studies varying significantly, some uncertainty in the value used is unavoidable.
- One of the peer reviewers commented on the way own consumption is considered. Generally it is assumed that it is included in the WTP, but it was argued that it should not be. We have included it in the WTP.

5 Climate change costs

5.1 Introduction

Due to the fact that the effects of climate change are global, long-term and have risk patterns that are difficult to anticipate, identifying the costs associated with these effects is extremely complex. Transport results in emissions of CO_2, N_2O and CH_4 (methane), all of which are greenhouse gases contributing to climate change. Therefore, identifying the climate costs of transport is extremely important. This chapter discusses the methodology to value the climate costs of transport.

In Section 5.2 we first briefly discuss the definition and scope of climate change costs. The total and average climate change costs are explored in Section 5.3, and the marginal climate change costs are the topic of Section 5.4. Finally, the robustness of the climate change cost figures presented in this chapter is analysed in Section 0. More detailed information on the effects of climate change and their monetary valuation can be found in Annex D.

5.2 Definition and scope

The emission of greenhouse gases into the atmosphere leads to global warming and climate change. The IPCC (2013) has estimated that without concrete climate policies temperatures may be expected to rise significantly by the end of the century. Such radical change will have an important and largely irreversible impact on ecosystems, human health and societies. Climate change costs are defined as the costs associated with all of the effects of global warming, such as sea level rise, biodiversity loss, water management issues, more and more frequent weather extremes and crop failures. For a more detailed discussion of the effects of climate change we refer to Annex D.2.

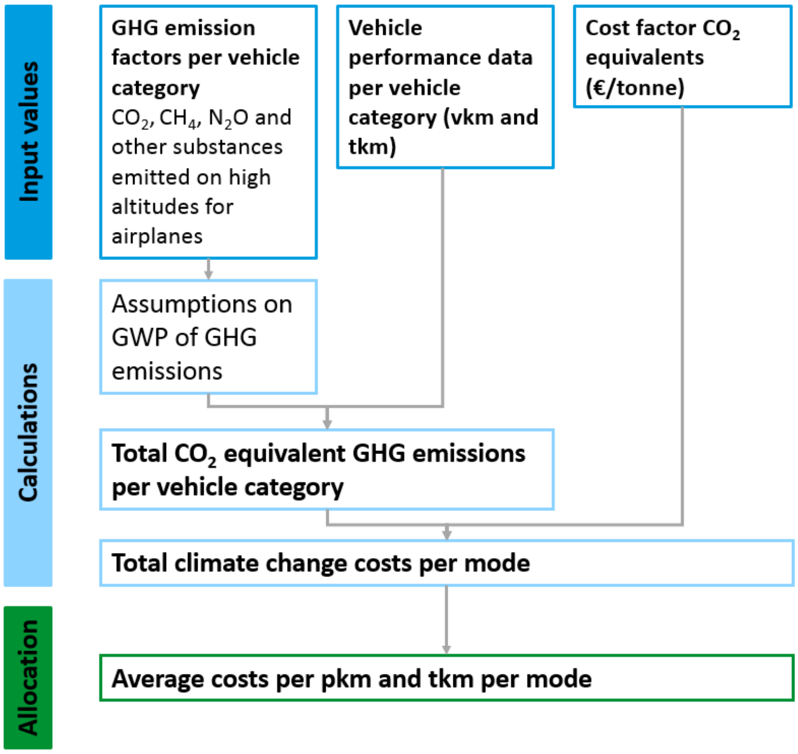
The climate change costs are calculated for all five transport modes. For road, (diesel-powered) rail, inland waterway and maritime transport, the global warming impacts of transport are mainly caused by CO_2, N_2O and CH_4. This chapter focusses on how to calculate the total, average and marginal costs of climate change for these transport modes. However, for aviation there are also other aircraft emissions such as water vapour, sulphate and soot aerosols which are harmful to the climate when emitted at high altitudes. We slightly adapt the methodology used for other transport modes to make it suitable to calculate the climate change costs from aviation (see the textbox in Section 5.3.1).
For maritime, it is important to note that a number of exhaust emissions (e.g. NO_x and SO_2) lead to (short-term) cooling effects, which implies that maritime transport currently has a net cooling effect on the global climate (Eyring, et al., 2009). Although it is complicated to compare the local, short-term cooling effects to the long term global warming effects, global warming potentials help this comparison (see textbox in Section 5.3.1).

5.3 Total and average climate change costs

5.3.1 Methodology

Total and average climate costs are calculated using a bottom-up approach. Figure 5 illustrates the corresponding methodology for road, rail, inland waterway, aviation and maritime transport. The methodology presented in this section is identical to the methodology used in both earlier editions of the Handbook for all transport modes.

Figure 5 – Methodology total and average climate change costs



Three input values are used: the GHG emission factors per vehicle type, vehicle performance data and the climate change costs per tonne of CO_2 equivalent. The GHG emissions per vehicle type can be calculated by multiplying the vehicle kilometres per vehicle type in each country with the vehicle emission factors (in g/km) for each of the various GHG (CO_2, N_2O, CH_4 and other aircraft emissions). Using Global Warming Potentials (GWP), the emissions of the three GHGs can be added together to achieve the total CO_2 equivalent GHG emissions (see Textbox). This is then multiplied by the climate change costs per tonne CO_2 equivalent in order to reach the total climate change costs per mode.
To reach the average climate change costs we divide the total climate change costs by the amount of pkms or tkms driven by the vehicle type.

Comparing CO_2 and non-CO_2 emissions
As mentioned earlier, climate change is not just triggered by CO_2 emissions. There are numerous other gases that result in climate change, although we limit ourselves to CO_2, N_2O, CH_4 and aviation emissions in this study. Aviation emissions, such as water vapour, sulphate and soot, can be particularly damaging when emitted at high altitudes although they may have contradicting effects. In part, these emissions result in heating effects (soot emissions from aircraft engines, night-time contrail formation, atmospheric chemical reactions on the basis of NO_X that increases ozone concentrations) and in part they result in cooling (sulphur aerosols, day-time contrail formation, atmospheric chemical reactions on the basis of NO_x that convert methane).

As these different emission gases differ in their lifetime and their potency it can be complicated to compare CO_2 emissions to non-CO_2 emissions. To allow for such comparisons, the concept of the **Global Warming Potential** (GWP) is used. The GWP is a relative measure, which compares the amount of heat trapped by a certain mass of gas to the amount of heat trapped by a similar mass of CO_2 over a certain period of time (e.g. 100 years). The GWP of CO_2 is standardised to 1. In the IPCC's latest Assessment Report (IPCC, 2013) the GWP over a 100-year time period of CH_4 and N_20 are 34 and 298 respectively. This implies that the same amount of CH_4 is 34 times more potent than the same amount of CO_2, when looking at a period of 100 years. These factors will be used to compare CO_2 emissions with N_2O and CH_4 emissions for road, rail, inland waterways and maritime transport in this Handbook.

To account for the emissions from aviation, GWPs are used as **Emission Weighting Factors** (Foster, et al., 2007). Studies shown that the EWF for aviation lies in the range of 1.3-1.4 (Lee, et al., 2009) (Azar & Johansson, 2012). This implies that the total climate change impact from aviation is 1.3-1.4 times larger than the impact from its CO_2 emissions alone. It is important to note that these estimates do not include the impacts of aviation induced cloudiness. If aviation induced cirrus is included, the uncertainty regarding EWF increases substantially, with values ranging from 1.3 to 2.9 (with 'best estimates' of 1.7-2.0) (Lee, et al., 2009) (Azar & Johansson, 2012).

An alternative methodology to determine the climate change impact from aviation uses the **Radiative Forcing Index**. This index represents the *ratio between the total radiative forcing from aviation at some given time to the radiative forcing from aviation emissions of CO_2 at the same time* (Forster, et al., 2006). Studies have suggested that the RFI lies between 2 and 4, indicating that the total climate impact of aviation at a certain point is 2-4 times larger than the impact of its CO_2 emissions alone (IPCC, 1999; Sausen, et al., 2005). However, one of the major weaknesses of the RFI is that it does not take into account the variation in the lifetime of different emissions. This variation is substantial, lifetimes range from just a few hours (contrails) to 10 years (aircraft induced methane reduction and its associated effects on ozone) and even up to 200 years (CO_2). Not taking into account these differences in lifetime, and simply multiplying the current amount of CO_2 emissions from aviation by a factor 2-4, would overestimate the long-term climate impact of aviation.

In this Handbook we use emission weighting factors to value the climate change impacts of aviation, as this methodology accounts for the differing lifetime of emissions, whereas the radiative forcing index does not. Although we acknowledge that the uncertainties for the emission weighting factors are somewhat larger when aviation-induced cirrus is included, we believe this is an important effect to take into account. Therefore, we will use a factor of 2 in this study to estimate the non-CO_2 climate impacts of high altitude emissions from aviation. This implies that the total CO_2 emissions from an aircraft are multiplied by a factor 2 to reach the total CO_2 equivalent emissions. This is the same value that was used in previous editions of the Handbook (Infras, CE Delft, ISI & University of Gdansk, 2008; Ricardo-AEA, TRT, DIW Econ & CAU, 2014) and in (HEATCO, 2006).

5.3.2 Input values

Three types of input values are needed in order to follow the methodology outlined above.

GHG emissions per vehicle type

In case the GHG emissions per vehicle type are not yet given, we need to first multiply the vehicle emission factors, in grams of CO_2, CH_4 and N_2O per kilometre driven, with the amount of vehicle kilometres driven by that vehicle type in each country. The sources for the emission factors of different modes of transport that are used in this study are shown in Table 13. The emission factors are real world emission factors from fleet averages. They are not based on vehicle type approval tests. The transport performance data and emission factors per country that was used is based on the sources from Table 13.

GWP of GHG emissions

To allow for comparisons between the different GHGs, the GHGs need to be made comparable to each other. The way to compare CO_2-emissions with non-CO_2 emissions is to use the concept of GWP (see Textbox in Section 5.3.1). GWP of CO_2 is standardised to 1. In the IPCC's latest Assessment Report (IPCC, 2013; Table 8.A.1, page 731) the GWP over a 100-year time period of CH_4 and N_20 are 30 and 265 respectively. In our calculations we will use these GWP's to be able to add the amounts of the different gases together, in order to present the results in terms of CO_2 equivalents. Currently European Union Legislation for Monitoring and Reporting Greenhouse Gas Emissions[17] uses GWPs from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. For the purposes of this handbook, it was, however decided to use the more recent 2013 IPCC estimates cited above. This can make a difference to the impacts caused by non-CO2 greenhouse gases.

Climate change costs per tonne of CO_2 equivalent

There are two major ways that the climate change costs can be monetised: either using a damage cost approach or an avoidance cost approach. Both methods are discussed in more detail in Annex D.3. Like in the previous versions of this Handbook, we use the avoidance cost approach. Damage costs have serious limitations because potentially catastrophic effects, such as the melting of the polar ice caps in Greenland or West Antarctica or changes in climate subsystems such as El Niño Southern Oscillation cannot be well incorporated. The GHG emission reductions agreed in the Paris Agreement are based on preventing temperature rises above 1.5-2 degrees Celsius. Exceeding this level is considered to be too risky for future generations. Therefore, it makes sense to formulate climate change costs as avoidance costs, based on the target agreed in the Paris Agreement. Limiting temperature rise to 1.5-2 degrees Celsius roughly equates to no more than 450 ppm (parts per million) CO_2 in the atmosphere. A wide range of literature on avoidance costs is available. The avoidance costs used in this Handbook are based on an analysis of recent literature which revealed that the central value for the short-and-medium-run costs (up to 2030) is € 100/tCO_2 equivalent (€$_{2016}$). The central value for the long run costs (up to 2060) is € 269/tCO_2 equivalent (€$_{2016}$). Table 24 shows a low and high estimate for these time

[17] COMMISSION IMPLEMENTING REGULATION (EU) No 749/2014 of 30 June 2014 on structure, format, submission processes and review of information reported by Member States pursuant to Regulation (EU) No 525/2013 of the European Parliament and of the Council, Recital (2) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0749&from=EN

periods, although we use the central estimates for the short-and-medium-run in this Handbook. These values were derived by calculating the average of the low, central and high estimates for the relevant time periods of the values from the literature, but excluding the lowest and highest values to eliminate outliers. For a full literature review of avoidance costs and our analysis we refer to Annex D.

Table 24 - Climate change avoidance costs in €/tCO_2 equivalent (€$_{2016}$)

	Low	Central	High
Short-and-medium-run (up to 2030)	60	100	189
Long run (from 2040 to 2060)	156	269	498

5.3.3 Output values

The following tables show the resulting cost factors (output values) for the climate costs per transport mode and vehicle type. The tables include the total costs as well as the average costs per vkm and per pkm or tkm. The calculations have been made based on the cost factor of € 100 per t CO_2 equivalent, the central value for short and medium run estimations (see section above).

Table 25 - Total and average climate change costs for land-based modes for the EU28

	Total costs EU28	Average costs	
Passenger transport	**Billion €**	**€-cent per pkm**	**€-cent per vkm**
Passenger car	55.56	1.18	1.90
Passenger car - petrol	32.02	1.22	1.97
Passenger car - diesel	23.54	1.12	1.80
Motorcycle	1.47	0.89	0.94
Bus	0.84	0.47	8.83
Coach	1.61	0.44	8.66
Total passenger road	**59.49**		
Passenger train diesel	0.22	0.34	20.1
Total passenger transport	**59.71**		
Freight transport	**Billion €**	**€-cent per tkm**	**€-cent per vkm**
LCV	13.17	3.98	2.75
LCV - petrol	0.71	3.76	2.56
LCV - diesel	12.45	3.99	2.77
HGV	9.63	0.53	6.48
Total freight road	**22.79**		
Freight train diesel	0.24	0.25	112.4
Inland Vessel	0.40	0.27	383.1
Total freight transport	**23.43**		
Total road, rail, inland waterway	**83.14**		

Table 26 - Total and average climate costs for aviation for selected 33 EU airports

Type of flight	Billion €	€-cent/pkm	€-cent/pax*
Short haul (< 1,500 km)	2.14	2.39	1,315
Medium haul (1,500-5,000 km)	5.50	1.85	3,341
Long haul (> 5,000 km)	14.37	2.24	17,629
Total	**22.01**	**2.14**	**5,383**

* Costs per pax are including the complete flight (not only the half-way principle).

Table 27 presents rough estimates for the average and total external climate change costs of maritime transport. These data are only available for freight. The average cost has been based on the cost for reference cases presented in Section 5.4 and data on the number of port calls for the selected ports from Eurostat. The total climate change cost has been based on the average cost and the number of tkms provided by DG MOVE[18]. The available data does not allow an estimate of costs at the individual port level.

Table 27 - Rough estimates for total and average external climate change costs for maritime transport for 34 selected EU ports

Transport mode	Total costs (bn €)	Average costs (€-cent/tkm)
Freight ship	11	0.16

5.4 Marginal climate change costs for selected cases

For climate change costs, the marginal costs are the same as the average costs. This is because the average and marginal climate emissions per kilometre of a vehicle are equal. This implies that an additional kg of CO_2 emitted leads to the same social (external) costs as the average kilogram CO_2 emitted, since the CO_2 is distributed in the whole atmosphere. Furthermore, the avoidance costs used in this Handbook are based on the entire economy and are not significantly dependent on the emissions of the transport sector.

The average climate costs for different modes and within the modes for different vehicle types, are calculated by multiplying the emission factors (in gram CO_2 equivalent per unit) with the avoidance costs of CO_2. These emission factors are deriven from the following sources:
- road transport: COPERT database;
- rail transport: TREMOD database;
- inland waterways: EcoTransit World database;
- aviation: TREMOD database.

The costs for road vehicles are presented for all differentiations provided by COPERT, e.g. different fuel types, engines or vehicle sizes, emission classes and regional areas. It needs to be emphasised that the Euro standard is not a cost driver for the climate costs. There are some differences between the results for the different Euro standards though, that are the result of the COPERT emission data. These differences are related to the improved energy efficiency over time and impacts of emission reduction technology on fuel efficiency.

The size classes for trucks from COPERT do not match with those for the Eurostat transport performance data used for this Handbook. The load factors for trucks have therefore been based on an interpolation of the Eurostat data.

18 See footnote 16.

Annex J contains the marginal climate cost data for road vehicles for reference cases that are defined in terms of the combination of fuel type and fuel efficiency of the vehicle (which are the main cost drivers for climate cost).

Table 28 on marginal climate change costs for road transport shows the costs per pkm or tkm (except for LCV, where costs per vkm are presented due to the fact that LCV have characteristics of freight and passenger transport). The costs per vkm for the different vehicle categories of road transport are available in the background Excel file.

Table 28 - Marginal climate change costs road transport for selected cases

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
Passenger transport (€-cent per pkm)						
Passenger Cars	Petrol	Mini < 0.8 l	Euro 4	0.87	0.84	0.72
			Euro 5	0.87	0.84	0.72
			Euro 6	0.87	0.84	0.72
		Small 0.8-1.4 l	Euro 0	1.25	1.53	1.06
			Euro 1	0.94	1.06	0.83
			Euro 2	0.90	1.05	0.77
			Euro 3	0.91	1.05	0.82
			Euro 4	0.96	1.09	0.85
			Euro 5	0.96	1.09	0.85
			Euro 6	0.96	1.09	0.85
		Medium 1.4-2.0 l	Euro 0	1.55	1.80	1.26
			Euro 1	1.07	1.29	0.96
			Euro 2	0.98	1.25	0.93
			Euro 3	1.08	1.26	0.96
			Euro 4	1.11	1.29	1.02
			Euro 5	1.11	1.29	1.02
			Euro 6	1.11	1.29	1.02
		Large-SUV-Executive > 2.0 l	Euro 0	1.79	2.21	1.50
			Euro 1	1.36	1.66	1.21
			Euro 2	1.34	1.70	1.27
			Euro 3	1.14	1.54	1.11
			Euro 4	1.31	1.89	1.31
			Euro 5	1.31	1.89	1.31
			Euro 6	1.31	1.89	1.31
	Diesel	Mini < 0.8 l	Euro 4	0.78	0.69	0.66
			Euro 5	0.78	0.69	0.66
			Euro 6	0.78	0.69	0.66
		Small 0.8-1.4 l	Euro 0	1.05	1.10	0.87
			Euro 1	1.05	1.10	0.87
			Euro 2	1.05	1.17	0.90
			Euro 3	0.97	1.11	0.88
			Euro 4	0.97	1.11	0.88
			Euro 5	0.97	1.11	0.88
			Euro 6	0.97	1.11	0.88
		Medium 1.4-2.0 l	Euro 0	1.22	1.29	1.02
			Euro 1	1.22	1.29	1.02
			Euro 2	1.23	1.33	1.04

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro 3	1.18	1.31	1.03
			Euro 4	1.18	1.31	1.03
			Euro 5	1.18	1.31	1.03
			Euro 6	1.18	1.31	1.03
		Large-SUV-Executive > 2.0 l	Euro 0	1.40	1.49	1.18
			Euro 1	1.40	1.49	1.18
			Euro 2	1.40	1.49	1.18
			Euro 3	1.39	1.50	1.18
			Euro 4	1.39	1.50	1.18
			Euro 5	1.39	1.50	1.18
			Euro 6	1.39	1.50	1.18
	Petrol Hybrid (PHEV)	Mini	Euro 4	0.57	0.44	0.44
		Small	Euro 4	0.57	0.44	0.44
		Large-SUV-Executive	Euro 4	0.57	0.44	0.44
	LPG Bifuel	Small	Euro 1	n.a.	n.a.	n.a.
			Euro 2	n.a.	n.a.	n.a.
			Euro 3	n.a.	n.a.	n.a.
			Euro 4	0.93	1.03	0.81
			Euro 5	0.89	0.98	0.77
			Euro 6	0.85	0.93	0.73
	CNG Biofuel	Small	Euro 4	0.81	0.89	0.69
			Euro 5	0.78	0.85	0.67
			Euro 6	0.74	0.81	0.63
	Electric (BEV)	n.a.	n.a.	0.00	0.00	0.00
Moped	Petrol	2-stroke < 50 cm³	Euro 0	0.78	0.78	0.78
			Euro 1	0.59	0.59	0.59
			Euro 2	0.59	0.59	0.59
			Euro 3	0.59	0.59	0.59
		4-stroke < 50 cm³	Euro 0	0.78	0.78	0.78
			Euro 1	0.59	0.59	0.59
			Euro 2	0.59	0.59	0.59
			Euro 3	0.59	0.59	0.59
Motorcycle	Petrol	2-stroke > 50 cm³	Euro 0	1.18	0.90	0.84
			Euro 1	1.08	0.82	0.77
			Euro 2	1.06	0.80	0.75
			Euro 3	1.06	0.80	0.75
		4-stroke < 250 cm³	Euro 0	1.25	0.86	0.94
			Euro 1	1.02	0.71	0.77
			Euro 2	0.77	0.63	0.61
			Euro 3	0.76	0.61	0.60
		4-stroke 250-750 cm³	Euro 0	1.35	1.23	1.07
			Euro 1	1.34	1.12	1.01
			Euro 2	1.23	1.02	0.92
			Euro 3	1.21	1.00	0.90
		4-stroke > 750 cm³	Euro 0	1.56	1.42	1.23
			Euro 1	1.36	1.38	1.12
			Euro 2	1.41	1.32	1.10

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro 3	1.39	1.32	1.09
	Electric	n.a.	n.a.	0.00	0.00	0.00
Urban buses	Diesel	Midi <=15 t	Euro 0	0.46	0.79	0.48
			Euro I	0.38	0.62	0.39
			Euro II	0.37	0.59	0.38
			Euro III	0.39	0.63	0.40
			Euro IV	0.39	0.57	0.40
			Euro V	0.37	0.56	0.36
			Euro VI	0.37	0.57	0.37
	Diesel	Standard 15-18 t	Euro 0	0.42	0.80	0.46
			Euro I	0.37	0.67	0.40
			Euro II	0.37	0.64	0.40
			Euro III	0.39	0.67	0.42
			Euro IV	0.39	0.61	0.42
			Euro V	0.36	0.60	0.38
			Euro VI	0.37	0.61	0.38
	Diesel	Articulated >18 t	Euro 0	0.43	0.82	0.48
			Euro I	0.39	0.70	0.43
			Euro II	0.39	0.67	0.43
			Euro III	0.40	0.70	0.44
			Euro IV	0.41	0.65	0.45
			Euro V	0.37	0.64	0.41
			Euro VI	0.38	0.65	0.41
	CNG	CNG buses	Euro I	0.99	0.99	0.99
			Euro II	0.89	0.89	0.89
			Euro III	0.74	0.74	0.74
			EEV	0.39	0.67	0.42
	Biodiesel	Biodiesel buses	Euro 0	0.37	0.70	0.40
			Euro I	0.33	0.58	0.35
			Euro II	0.33	0.56	0.35
			Euro III	0.34	0.58	0.36
			Euro IV	0.34	0.54	0.36
			Euro V	0.31	0.52	0.33
			Euro VI	0.32	0.54	0.33
	Electric	Small	n.a.	0.00	0.00	0.00
		Medium	n.a.	0.00	0.00	0.00
		Large	n.a.	0.00	0.00	0.00
Coaches	Diesel	Standard <=18 t	Euro 0	0.41	0.90	0.46
			Euro I	0.37	0.81	0.42
			Euro II	0.37	0.80	0.43
			Euro III	0.40	0.88	0.46
			Euro IV	0.40	0.81	0.45
			Euro V	0.40	0.80	0.44
			Euro VI	0.40	0.82	0.46
	Diesel	Articulated > 18 t	Euro 0	0.33	0.73	0.37
			Euro I	0.29	0.63	0.33
			Euro II	0.29	0.62	0.33
			Euro III	0.28	0.66	0.33
			Euro IV	0.28	0.61	0.32

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro V	0.30	0.61	0.34
			Euro VI	0.30	0.62	0.35
Light commercial vehicles (€-cent per vkm)						
Light Commercial Vehicles	Petrol		Euro 0	2.38	3.52	2.15
			Euro 1	2.38	3.52	2.15
			Euro 2	2.37	3.47	2.12
			Euro 3	2.34	3.40	2.07
			Euro 4	2.34	3.38	2.06
			Euro 5	1.47	1.89	1.36
			Euro 6	1.47	1.89	1.36
	Diesel		Euro 0	2.82	2.57	1.89
			Euro 1	2.82	2.57	1.89
			Euro 2	2.82	2.57	1.89
			Euro 3	2.82	2.58	1.88
			Euro 4	2.82	2.58	1.88
			Euro 5	2.31	2.40	2.03
			Euro 6	2.31	2.40	2.03
	Electric		n.a.	0.00	0.00	0.00
Freight transport (€-cent per tkm)						
HGV	Diesel	Rigid <=7,5 t	Euro 0	4.52	5.48	4.36
			Euro I	4.18	4.45	3.63
			Euro II	4.05	4.17	3.51
			Euro III	4.26	4.46	3.67
			Euro IV	4.33	4.19	3.67
			Euro V	4.30	4.03	3.56
			Euro VI	4.29	4.12	3.59
		Rigid 7,5-12 t	Euro 0	2.32	3.22	2.33
			Euro I	2.10	2.67	2.05
			Euro II	2.06	2.53	1.99
			Euro III	2.13	2.68	2.08
			Euro IV	2.13	2.53	2.06
			Euro V	2.22	2.54	1.96
			Euro VI	2.23	2.59	1.98
		Rigid 12-14 t	Euro 0	1.33	1.90	1.34
			Euro I	1.19	1.60	1.18
			Euro II	1.16	1.52	1.14
			Euro III	1.19	1.61	1.19
			Euro IV	1.19	1.50	1.17
			Euro V	1.10	1.47	1.15
			Euro VI	1.11	1.50	1.16
		Rigid 14-20 t	Euro 0	1.50	2.40	1.58
			Euro I	1.27	1.92	1.31
			Euro II	1.24	1.82	1.28
			Euro III	1.27	1.93	1.32
			Euro IV	1.25	1.76	1.29
			Euro V	1.18	1.77	1.26
			Euro VI	1.19	1.77	1.27
		Rigid 20-26 t	Euro 0	0.83	1.40	0.90
			Euro I	0.73	1.18	0.78

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro II	0.71	1.13	0.76
			Euro III	0.72	1.18	0.78
			Euro IV	0.71	1.10	0.76
			Euro V	0.69	1.10	0.75
			Euro VI	0.69	1.11	0.75
		Rigid 26-28 t	Euro 0	0.62	1.05	0.68
			Euro I	0.54	0.89	0.59
			Euro II	0.53	0.85	0.58
			Euro III	0.54	0.89	0.59
			Euro IV	0.54	0.84	0.58
			Euro V	0.53	0.82	0.57
			Euro VI	0.53	0.84	0.58
		Rigid 28-32 t	Euro 0	0.57	0.92	0.62
			Euro I	0.51	0.81	0.55
			Euro II	0.52	0.80	0.54
			Euro III	0.51	0.81	0.56
			Euro IV	0.51	0.77	0.55
			Euro V	0.50	0.75	0.54
			Euro VI	0.50	0.77	0.55
		Rigid >32 t	Euro 0	0.49	0.84	0.54
			Euro I	0.44	0.73	0.48
			Euro II	0.43	0.70	0.47
			Euro III	0.44	0.73	0.48
			Euro IV	0.43	0.69	0.47
			Euro V	0.42	0.69	0.46
			Euro VI	0.42	0.69	0.47
		Articulated 14-20 t	Euro 0	0.80	1.33	0.86
			Euro I	0.69	1.09	0.73
			Euro II	0.67	1.04	0.71
			Euro III	0.69	1.10	0.74
			Euro IV	0.68	1.02	0.72
			Euro V	0.66	1.00	0.71
			Euro VI	0.66	1.02	0.71
		Articulated 20-28 t	Euro 0	0.79	1.35	0.87
			Euro I	0.71	1.19	0.77
			Euro II	0.68	1.12	0.75
			Euro III	0.70	1.17	0.77
			Euro IV	0.69	1.10	0.76
			Euro V	0.68	1.08	0.74
			Euro VI	0.68	1.09	0.75
		Articulated 28-34 t	Euro 0	0.49	0.84	0.54
			Euro I	0.44	0.75	0.49
			Euro II	0.44	0.72	0.47
			Euro III	0.43	0.74	0.48
			Euro IV	0.43	0.70	0.48
			Euro V	0.43	0.69	0.47
			Euro VI	0.43	0.69	0.47
		Articulated 34-40 t	Euro 0	0.48	0.87	0.54
			Euro I	0.43	0.75	0.48

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro II	0.42	0.73	0.47
			Euro III	0.42	0.76	0.48
			Euro IV	0.42	0.71	0.47
			Euro V	0.42	0.71	0.46
			Euro VI	0.42	0.72	0.47
		Articulated 40-50 t	Euro 0	0.45	0.82	0.51
			Euro I	0.40	0.71	0.45
			Euro II	0.41	0.71	0.45
			Euro III	0.40	0.72	0.46
			Euro IV	0.40	0.68	0.45
			Euro V	0.40	0.68	0.45
			Euro VI	0.40	0.69	0.45
		Articulated 50-60 t	Euro 0	0.47	0.86	0.54
			Euro I	0.43	0.77	0.47
			Euro II	0.42	0.74	0.47
			Euro III	0.43	0.77	0.47
			Euro IV	0.42	0.73	0.47
			Euro V	0.42	0.72	0.47
			Euro VI	0.43	0.73	0.47
	LNG	Articulated 32+	n.a.	0.21	0.36	0.23

Table 29 – Marginal climate change costs rail transport for selected cases

Train type	Traction	€-cent/pkm or €-cent/tkm	€-cent/train-km
Passenger transport			
Intercity train	Diesel	0.201	17.5
Regional train	Diesel	0.735	22.8
Freight transport			
Long container	Diesel	0.158	118.2
Long bulk	Diesel	0.087	122.5
Short container	Diesel	0.074	103.2
Short bulk	Diesel	0.066	105.9

Climate change costs for electric trains are zero. Emissions occur only during electricity generation, which is covered in Chapter 8 including the cost of well-to-tank emissions.

Table 30 - Marginal climate change costs IWT for selected cases

Vessel type	Type of cargo	€-cent/tkm	€-cent/vkm
CEMT II (350 t)	Bulk	0.34	107
	Container	0.21	107
CEMT IV (600 t)	Bulk	0.20	159
CEMT Va (1,500 t)	Bulk	0.18	290
	Container	0.21	290
Pushed convoy (11,000 t)	Bulk	0.15	777
	Container	0.11	777

Table 31 - Marginal climate change costs maritime transport for selected cases

Vessel type	Distance at sea (km)	€ per port call	€-cent per pkm or tkm	€ per vessel-km
Passenger transport				
RoPax Ferry (25,500 gt)	100	5,800	10.98	58.0
	500	14,598	5.53	29.2
Freight transport				
Small container vessel (28,500 gt)	500	40,876	0.34	81.8
	3,000	134,753	0.19	44.9
Large container vessel (143,000 gt)	500	61,795	0.11	123.6
	3,000	291,770	0.08	97.3
	15,000	1,395,651	0.08	93.0
Small bulk vessel (18,000 gt)	500	11,939	0.16	23.9
	3,000	51,631	0.11	17.2
Large bulk vessel (105,000 gt)	500	29,092	0.06	58.2
	3,000	119,549	0.04	39.8
	15,000	553,747	0.04	36.9

Table 32 - Marginal climate change costs aviation for selected cases

Type of flight	Distance (km)	Emission class	Example of aircraft type	€-cent per pkm	€ per pax
Short haul	500	Low	Bombardier CRJ900	2.84	14
	500	High	Embraer 190	3.44	17
Medium haul	1,500	Low	Airbus 320	1.53	23
	1,500	High	Boeing 737	2.18	33
	3,000	Low	Airbus 320	1.43	43
	3,000	High	Boeing 737	2.04	61
Long haul	5,000	Low	Airbus 340	1.17	58
	5,000	High	Boeing 777	1.32	66
	15,000	Low	Airbus 340	1.56	234
	15,000	High	Boeing 777	1.77	265

The marginal costs of aviation for selected cases and aircrafts cannot be directly compared with the average costs: The marginal costs refer to very specific aircraft types, distances and loading factors that do not match the average. E.g. for short haul flights, the average number of passenger per flight is substantially higher than for the selected cases (since many short haul flights are done by larger aircraft). Additionally, the average distances are different than the one use in the selected cases.

5.5 Robustness of results

We have calculated the climate change costs according to the most recent and high quality evidence and methods. Nonetheless, there are a few aspects that merit a point of discussion regarding the robustness of the results presented in this chapter.

Firstly, we have used avoidance costs, rather than damage costs, to monetise the costs of climate change. Our literature review confirmed that, the use of avoidance costs is a superior method to the use of damage costs (see full discussion in Section D.3).

However, uncertainties will always remain. We have attempted to take away some of that uncertainty by providing high and low case climate change costs, which can be used as a sensitivity analysis.

Furthermore, there can be political reasons, related to distributional or competitiveness aspects, which lead to political decisions to apply different mitigation costs in different sectors

6 Noise costs

6.1 Introduction

Traffic noise is generally experienced as a disutility and is accompanied by significant costs. Noise emissions from traffic pose a growing environmental problem due to the combination of a trend towards greater urbanisation and an increase in traffic volumes. Whilst the increase in traffic volume results in higher noise levels, the increase in urbanisation results in a higher number of people experiencing disutility due to noise. As a result, the costs of traffic noise are expected to grow in the future despite potential noise-reducing improvements in vehicles, tyres and roads.

In this chapter we provide an overview of the recommended approaches to value noise costs, as well as an overview of recommended noise cost figures. In Section 6.2 we first briefly discuss the definition and scope of noise costs. The total and average noise costs are explored in Section 6.3, and the marginal noise costs are the topic of Section 0. Finally, the robustness of the noise cost figures presented in this chapter is analysed in Section 6.5. More detailed information on noise costs can be found in Annex E.

6.2 Definition and scope

In general, noise can be defined as unwanted sounds of varying duration, intensity or other quality that causes physical or psychological harm to humans (CE Delft, INFRAS & Fraunhofer ISI, 2011). In this study, we will consider noise costs for the following transport modes: road, rail and aviation. Noise costs for inland waterway transport and maritime transport are considered negligible or non-existent as they usually take place in sparsely populated areas and the noise emission factors for those transport modes are relatively low and so are not covered in this chapter.

Unit

The basic measurement index for noise is the decibel (dB). It is indexed logarithmically, reflecting the logarithmic manner in which the human ear responds to sound pressure. Within the human range of hearing, deep and very high tones at the same sound intensity are experienced as less noisy. To correct for this sensitivity, a frequency weighting is applied to measurements and calculations. The most common frequency weighting is the 'A weighting', dB(A).

The logarithmic nature of noise is also reflected in the relationship between noise and traffic volume. Halving or doubling the amount of traffic results in a change of 3 dB, irrespective of the current flow. Thus an increase in traffic volume from 50 to 100 vehicles results in the same increase in noise level as doubling transport volume from 500 to 1,000 vehicles.

An important aspect is the time of day at which the noise takes place. In this study we employ the measure $L_{day, evening, night}$ (L_{den}), the current legal measure for traffic noise. Lden is a weighted average of the total noise during day, evening and night times. One fundamental feature of L_{den} is that it assumes that evening- and night-time noise is more of a nuisance than day-time noise[19].

The thresholds above which noise is considered a nuisance are somewhat arbitrary, previous literature has employed thresholds of 50, 55 and 60 dB(A). It is important to note that the

[19] Evening noise is given a penalty of 5 dB(A). Night-time noise is given a 10 dB(A) penalty.

choice of a threshold has a substantial impact on marginal noise costs. In this study we propose to use the threshold of 50 dB(A). This threshold was chosen as it is one that is least likely to result in an underestimation of the noise costs. However, the EEA Noise Maps which are used as input data in this study only start from 55 dB(A), therefore we only have the number of people exposed to noise above 55 dB(A). Ideally, the number of people exposed to noise levels between 50 and 55 dB(A) would also be included, however, due to data limitations of the EEA noise maps, this was not feasible in this edition of the Handbook.

Numerous studies have proposed the concept of a rail bonus, the notion that noise as a result of rail transport is experienced as less of a nuisance than road noise. It gives rail transport a 5 dB 'discount' in comparison to road noise and was widely used in noise directives. In contrast to previous editions of the Handbook we don't incorporate the rail bonus in this edition of the Handbook. This is based on an extensive literature review, which suggests that recent literature cannot support the upholding of the rail bonus (see Annex E.4).

Effects of noise

The exposure to noise results in a number of health endpoints due to prolonged and frequent exposure to transport noise. These health endpoints can take a multitude of forms. Health endpoints for which significant evidence is available are ((WHO, 2011; (WHO, 2017-2018); (Defra, 2014)):

- ischaemic heart disease;
- stroke;
- dementia;
- hypertension;
- annoyance.

Grouping annoyance under the health endpoints of noise exposure is consistent with the WHO definition of health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 1946). Annoyance represents the disturbance individuals experience when they are exposed to traffic noise. It can hinder people in performing certain activities, which may lead to a variety of negative responses, including irritation, disappointment, anxiety, exhaustion and sleep disturbance (WHO, 2011). However, annoyance is measured in a different way to the other 'more classical' health impacts, and therefore we have made the somewhat arbitrary distinction to look at annoyance separately from the other health impacts. This was decided because the valuation of annoyance applied is very different from the valuation of the other health endpoints.

The cost components are closely linked. For instance, sleep disturbance is classified as a health endpoint according to (Defra, 2014), although there is likely to be significant overlap with annoyance. These two impacts are difficult to separate. In WTP studies looking at noise it is complicated to separate individual's valuation for annoyance from sleep disturbance. If one is asked about their annoyance they are inclined to also take into account the effects of sleep disturbance. Therefore, there is an implicit risk of double counting the valuation if both sleep disturbance and annoyance impacts are explicitly taken into account. To avoid double counting we employ the conservative assumption that we include both the annoyance and health costs of noise, but exclude sleep disturbance from the health endpoints. It is possible that this leads to a small underestimate of the true costs of noise.

For health endpoints not mentioned in the list above, e.g. breast cancer and depression, only fragmented evidence is available. Therefore, these costs are not included in the noise costs estimated in this study. For the same reason, productivity losses (e.g. due to loss of concentration) and environmental impacts of traffic noise (e.g. harmful effects on wildlife) are not covered. Finally, direct material damages as a result of vibrations are not included in the costs of noise in this study, as the vibrations are not necessarily an effect of noise, but rather an external effect on its own. For a more detailed discussion on the effects of noise we refer to Annex E.

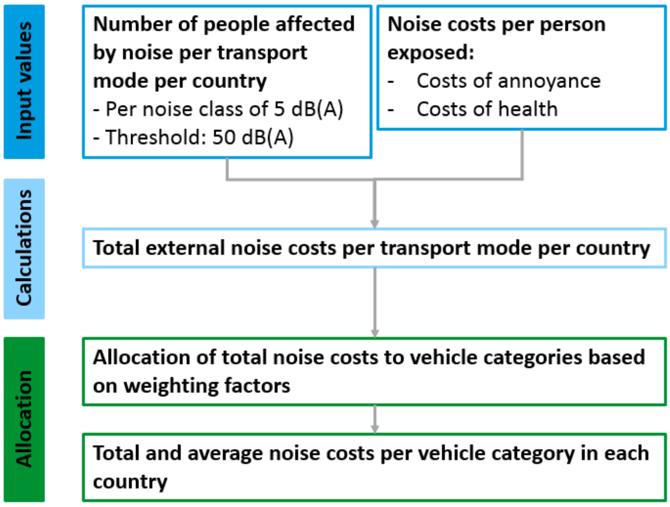
6.3 Total and average noise costs

6.3.1 Methodology

Total and average noise costs are calculated using a bottom-up approach. Figure 6 illustrates the corresponding methodology.

There are two types of input value: the number of people exposed to noise for each transport mode, and the noise costs per person exposed. The noise classes that people are exposed to are classified in bins, e.g. of 5 dB(A). For each noise class and transport mode, the total number of people exposed has to be calculated. The other input value, the noise costs per person exposed, consists of two values, an annoyance value and a health value. The annoyance value is calculated using a WTP approach, where respondents are asked how much they are willing to pay for changes in the noise level. The health value is based on an environmental burden of disease method and are taken from (Defra, 2014). Summing the health value and the annoyance value results in the total noise costs per person exposed. These costs per person are multiplied with the number of people exposed to the corresponding noise level. Summing these costs together gives the total external noise costs for a transport mode (road, rail or aviation). The total costs are allocated to specific vehicle categories (e.g. passenger cars, motorcycles, busses) based on weighting factors based on (CE Delft, INFRAS & Fraunhofer ISI, 2011; CE Delft & VU, 2014; VROM, 2006) in order to estimate the total costs per vehicle category. Finally, average noise costs are estimated by dividing the total costs by total transport performance (e.g. pkm, tkm, etc.).

Figure 6 – Methodology total and average noise costs



6.3.2 Input values

Three types of input values are needed in order to follow the methodology described above.

People exposed

In order to calculate total and average noise costs for a country, the number of people exposed to a certain noise level (in bins of 5 dB(A)) originating from a certain transport mode is needed. This data is preferably based on national data (empirical data or specific national model calculations). A second-best option (applied in this study to estimate total and average noise costs for European countries) is to make use of EU-wide data that is available from the noise maps from the EEA. Directive 2002/49/EC (EC, 2002) requires Member States to provide data on the number of people exposed to road, rail or aviation noise in their countries to the European Commission. This data is highly useful, although there are also data gaps. For instance, not all data has been reported and not all cities and urban regions are included in the scope of the noise directive. Therefore, we have carried out corrections in order to make the data more complete. For details on the corrections, we refer to Annex E.

Environmental prices

The environmental price of noise reflects the welfare loss that occurs with one extra decibel of noise (CE Delft, 2018). The environmental price of noise needs to be determined implicitly, as there is no market for noise prevention. Previous editions of the Handbook have recommended using environmental prices based on HEATCO (2006), both for annoyance and health endpoints. HEATCO assumes a constant valuation per dB of noise for annoyance costs, which has recently been disputed. This Handbook therefore uses increasing prices per dB based on the most recent insights provided by (Bristow, et al., 2015) for annoyance costs. As for health costs, the prices according to (Defra, 2014) match the WHO's recommendations in their latest systematic reviews, and are therefore used in this Handbook. For a more detailed discussion on the evidence for the environmental prices of noise we refer to Annex E.

The recommended environmental prices for noise (EU28 averages), including both health and annoyance costs, are shown in Table 33. Tables with the environmental price of noise per country are provided in the database.

Table 33 - Environmental price of traffic noise for the EU28 (€2016/dB/person/year)

Lden	Road transport			Rail transport			Aviation		
(db(A))	Annoyance	Health	Total	Annoyance	Health	Total	Annoyance	Health	Total
50-54	14	3	**17**	14	3	**17**	34	5	**39**
55-59	28	3	**31**	28	4	**32**	68	6	**74**
60-64	28	6	**34**	28	6	**34**	68	9	**77**
65-69	54	9	**63**	54	9	**63**	129	12	**141**
70-74	54	13	**67**	54	13	**67**	129	16	**145**
≥ 75	54	18	**72**	54	18	**72**	129	21	**150**

Weighting factors for different vehicles

To be able to allocate the total noise costs per transport mode to noise costs per vehicle class, the total kilometres travelled by each vehicle class needs to be known.
However, noise originating from certain types of vehicles (e.g. trucks) is considered more of a nuisance than noise from others (e.g. passenger cars). To reflect this, different weighting factors are applied. Like in previous versions of this Handbook, it is assumed that the weighting factors are identical for all countries. Table 34 illustrates the weighting factors used in this study, which are based on (CE Delft, INFRAS & Fraunhofer ISI, 2011; CE Delft & VU, 2014; VROM, 2006).

Table 34 - Weighting factors for noise for different vehicle types

	Urban (50 km/h)	Other roads (80 km/h or higher)
Road		
Passenger car	1.0	1.0
Passenger car petrol	1.0	1.0
Passenger car diesel	1.2	1.0
Motorcycle	13.2	4.2
LCV	1.5	1.2
Bus/coach	9.8	3.3
HGV 3.5-7.5 t	9.8	3.0
HGV 7.5-16 t	13.2	4.2
HGV 16-32 t	14.9	4.8
HGV > 32 t	16.6	5.5
Rail		
Passenger train	1	
Freight train	4	

6.3.3 Output values

Table 35 describes the total and average noise costs in the EU as a whole for road and rail transport. Costs at the country level are provided in the database. For road transport, the total costs originating from transport via a motorway are also provided in the database.

Table 35 - Total and average noise costs for land-based modes for the EU28

Transport mode	Total costs EU28	Average costs	
Passenger transport	**Billion €**	**€-cent per pkm**	**€-cent per vkm**
Passenger car	26.2	0.6	0.9
Passenger car - petrol	13.8	0.5	0.8
Passenger car - diesel	12.4	0.6	0.9
Motorcycle	14.8	9.0	9.4
Bus	0.8	0.4	8.0
Coach	0.9	0.2	4.7
Total passenger road	**42.6**		
High speed passenger train	0.4	0.3	97
Passenger train electric	2.6*	0.8	106
Passenger train diesel	0.9	1.4	81
Total passenger rail	**3.9**		
Total passenger transport	**46.5**		
Freight transport	**Billion €**	**€-cent per tkm**	**€-cent per vkm**
LCV	5.4	1.6	1.1
HGV 3.5-7.5 t	1.0	1.2	4.0
HGV 7.5-16 t	1.8	0.8	5.7
HGV 16-32 t	3.0	0.4	6.5
HGV > 32 t	3.2	0.4	7.2
Total freight road	**14.5**		
Freight train electric	2.1	0.6	359
Freight train diesel	0.4	0.4	201
Total freight rail	**2.5**		
Total freight transport	**17.1**		
Total road, rail, inland waterway	**63.6**		

* Total costs without highspeed passenger trains (average costs for passenger train electric: incl. high speed trains).

Table 36 illustrates the average costs of both passenger and freight aviation. Passenger aviation values are provided per LTO, passenger and pkm. The average costs of freight aviation are provided per LTO, tonne and tkm. Costs at the airport level are provided in the annex/database.

Table 36 - Total and average noise costs for aviation for 33 selected EU airports

Transport mode	Total costs	Average costs			
Passenger aviation	**Billion €**	**€/LTO**	**€/passenger**	**€/tonne**	**€-cent/pkm**
Short haul	0.84	257	2.05	9.04	0.46
Medium haul					0.11
Long haul					0.01

* Costs per pax are including the complete flight (not only the half-way principle).

6.4 Marginal noise costs

6.4.1 Methodology

Marginal noise costs differ from average noise costs for several reasons, butmainly because local factors influence the noise level and the damage and annoyance level. There are three main cost drivers for marginal noise costs:

- **Population density**: The population density close to the noise source is relevant for the number of people exposed to the noise. The closer to an emission source people live, the more nuisance will occur, and the higher the marginal costs will be. In the following section we roughly distinguish between three area types (urban, suburban, rural), representing different population densities. In general, the population density will be highest in urban (metropolitan) areas and lowest in rural areas.
- **Existing noise levels** (depending on traffic volume, traffic mix and speed): If there is an additional vehicle on an already busy urban road, the additional (marginal) noise costs are small compared to a comparable situation along a rural road with little traffic. The higher the existing background noise level, the lower the marginal costs of an additional vehicle. As a proxy for the existing noise levels, three different area types (urban, suburban, and rural) and two different traffic situations (thin or dense traffic) are distinguished.
- **Time of the day:** Epidemiological studies show that the noise induced health effects during the night are higher than during the day as a consequence of sleep disturbance. Therefore, noise disturbances at night will lead to higher marginal costs than during the day. In the following section, marginal noise costs are differentiated for night and day.

For road and rail transport the marginal noise costs are estimated based on the earlier calculations of marginal costs in CE/INFRAS/ISI (2011) and INFRAS/IWW (2004). For deriving up-to-date marginal noise costs based on the aforementioned marginal noise cost studies, the development of the average noise costs per transport mode and vehicle type over time, i.e. between the two older studies and the average noise costs calculated in the present Handbook (see Section 6.3.3), has been taken into account.

Marginal noise costs for aviation depend heavily on local factors (e.g. population density around airports), flight path, aircraft type and technology, and time of the day. Additionally, the noise level of one single flight movement is much higher than the average noise level. Therefore, it is very difficult to present an accurate (range of) marginal noise cost values that could be applied for all situations. Some earlier studies estimate the marginal noise costs of aviation (i.e. the cost per movement or per pax) to be around 30-60% of the average noise costs (per movement) for different transport situations or aircraft types. This means those studies state that the marginal costs of an additional flight movement are around a factor of 0.3 to 0.6 of the average noise costs (i.e. significantly lower than the average costs). Additionally, there are different studies expressing directly marginal noise costs for specific aircraft types, mainly based on a hedonic pricing approach (e.g. (Pearce & B.Pearce, 2000) (CE Delft, 2003), (TRL, 2001). In the next chapter, marginal noise costs are shown for both approaches.

6.4.2 Output values

The following tables include the marginal noise costs for road and rail transport, differentiated by vehicle type, time of the day, traffic situation and area type.

Table 37 on marginal noise costs for road transport shows the costs per pkm or tkm (except for LCV, where costs per vkm are presented due to the fact that LCV have characteristics of freight and passenger transport). The costs per vkm for the different vehicle categories of road transport are available in the background Excel file.

Table 37 – Marginal noise costs road transport - in €-cent (2016) per pkm, tkm or vkm (data for 2016)

Road	Time of the day	Traffic situation	Urban	Suburban	Rural
Passenger transport (€-cent per pkm)					
Passenger car	Day	Dense	0.5	0.03	0.004
		Thin	1.1	0.07	0.009
	Night	Dense	0.9	0.05	0.007
		Thin	2.1	0.13	0.015
Motorcycle	Day	Dense	7.4	0.4	0.06
		Thin	18.0	1.2	0.14
	Night	Dense	13.5	0.8	0.11
		Thin	32.7	2.1	0.24
Bus	Day	Dense	0.5	0.03	0.004
		Thin	1.3	0.08	0.010
	Night	Dense	1.0	0.05	0.008
		Thin	2.4	0.15	0.018
Coach	Day	Dense	0.3	0.02	0.002
		Thin	0.7	0.04	0.005
	Night	Dense	0.5	0.03	0.004
		Thin	1.2	0.08	0.009
Light commercial vehicles (€-cent per vkm)					
LCV	Day	Dense	1.7	0.1	0.01
		Thin	4.1	0.3	0.03
	Night	Dense	3.0	0.2	0.03
		Thin	7.4	0.5	0.06
Freight transport (€-cent per tkm)					
HGV average	Day	Dense	0.7	0.04	0.01
		Thin	1.6	0.11	0.01
	Night	Dense	1.2	0.07	0.01
		Thin	3.0	0.19	0.02
HGV 3.5-7.5 t	Day	Dense	1.5	0.08	0.01
		Thin	3.6	0.23	0.03
	Night	Dense	2.7	0.15	0.02
		Thin	6.5	0.42	0.05
HGV 7.5-16 t	Day	Dense	0.7	0.04	0.01
		Thin	1.8	0.11	0.01
	Night	Dense	1.3	0.07	0.01
		Thin	3.2	0.21	0.02
HGV 16-32 t	Day	Dense	0.6	0.03	0.00
		Thin	1.3	0.09	0.01
	Night	Dense	1.0	0.06	0.01
		Thin	2.4	0.16	0.02
HGV > 32 t	Day	Dense	0.6	0.03	0.00
		Thin	1.4	0.09	0.01
	Night	Dense	1.1	0.06	0.01
		Thin	2.6	0.17	0.02

Table 38 - Marginal noise costs rail transport - in €-cent (2016) per pkm and tkm (data for 2016)

Road	Time of the day	Traffic situation	Metropolitan	Urban	Rural
Passenger transport (€-cent per pkm)					
High speed train	Day	Dense	0.13	0.07	0.01
		Thin	0.21	0.12	0.02
	Night	Dense	0.23	0.13	0.02
		Thin	0.38	0.21	0.03
Conventional passenger train	Day	Dense	0.45	0.20	0.03
		Thin	0.74	0.33	0.05
	Night	Dense	0.82	0.36	0.05
		Thin	1.35	0.59	0.09
Freight transport (€-cent per tkm)					
Freight train	Day	Dense	0.13	0.05	0.01
		Thin	0.17	0.08	0.01
	Night	Dense	0.24	0.09	0.01
		Thin	0.39	0.15	0.02

There are no studies available that give more differentiated data for marginal rail noise costs (e.g. per train type or train length).

For marginal noise costs there is a number of studies that directly show the costs per aircraft type. However, the corresponding studies are all at least 5-10 years old. Still, they can be regarded as a good and sound basis for marginal costs of aircraft noise.

Table 39 – Marginal noise costs for aviation: data for different aircraft types

Aircraft type	Marginal noise costs per LTO (€$_{2016}$/LTO)
A 310	54
A 340	122
B 737-400	54
B 747-400	266
B 757	70
B 767-300	85
B 777	52
MD82	78

Source: Own calculations based on Pearce and Pearce (2000).

Alternatively, the marginal noise costs can be derived from the average costs, based on the methodology of UIC (CE Delft, INFRAS & Fraunhofer ISI, 2011) assuming that the marginal noise costs per movement (or per pkm or pax) are around 30 to 60% of the average noise costs. Based on the results of the average noise costs of aviation (see Section 6.3 above), this leads to the following range of marginal costs. The resulting costs per LTO are between 77 and 154 €$_{2016}$, whereas in the table above the range is between 52 and 266 €$_{2016}$ (for most between 52 and 122 €$_{2016}$). One reason for the slightly higher costs per LTO in the table below might be the fact that it includes all relevant effects, health costs and annoyance costs, whereas the data above are based on hedonic pricing studies, which do not cover the health costs.

Table 40 – Marginal noise costs for aviation, estimations based on average costs (data for 2016)

Transport type	Unit		Average costs	Marginal costs	
				Lower boundary	Upper boundary
Passenger	€/LTO		257	77	154
	€/passenger		2.1	0.6	1.2
	€-cent/ pkm	Average	0.08	0.02	0.05
		Short haul	0.09	0.03	0.06
		Medium haul	0.03	0.008	0.017
		Long haul	0.01	0.004	0.008

6.5 Robustness of results

The robustness of the results presented in this chapter is largely dependent on the EEA's noise maps. There are a number of factors related to the noise maps that could influence the robustness of the overall results.

Firstly, as there are regions for which data is missing in those maps, or regions that have no reporting obligation, corrections have been carried out to take into account these aspects. These corrections are more extensive than any other corrections that were carried out in earlier editions of the Handbook. A full description of the corrections that have been carried out can be found in Section E.2. Ideally, the noise maps would be complete for all countries and all regions. However, given the current data situation, this is unfeasible. Carrying out corrections to the data, as we have done in this Handbook, is likely to improve the robustness of results compared to the situation with no corrections. Having a complete EEA noise map is likely to further improve the robustness of the results.

Secondly, the latest noise maps are those for the year 2012, with data submitted up until 31/03/2017. It is possible that a substantial change in noise exposure has taken place between 2012 and 2016. As the magnitude and direction of this change is unclear, working with the 2012 noise maps is the best we can currently do. The robustness of results could be significantly improved if more current noise maps were available.

Thirdly, the results for road transport are affected by the transport performance data used. As explained in Section 1.3.4, in this study we use data from Eurostat, following the nationality principle, i.e. transport activity is allocated to countries where the vehicle is registered . The use of these data affects the results of this study, since the scope of these data differs from the scope of the noie maps, which is in line with the territorial principle. Particularly the results for HGVs may be significantly affected at country level. For example, in countries with a lot of transit traffic (e.g. Austria) a significant part of the noise costs should be allocated to foreign vehicles. By using transport performance data based on the nationality principle, transport activity of these foreign vehicles is not taken into account in the calculations.

Furthermore, the results for motorcycles should be interpreted with caution. This is because they are highly influenced by the transport performance data we have collected for motorcycles. Some national values show extremely high vehicle kilometres travelled by motorcycles, e.g. Italy and Spain, which raises the question if these values might include kilometres driven by mopeds too. Furthermore, almost half of the vehicle kilometres driven by motorcycles at the EU28 level are driven on urban roads, where the noise weighting factor for motorcycles is 13.2 times higher than the noise weighting factor for passenger cars. This also significantly influences the noise costs for motorcycles.

In addition, it is important to note that the WHO recently presented new exposure response functions. Unfortunately, within the scope of this project we could not fully develop new cost factors based on new exposure response functions. Therefore we use the closest ready-to-use values from the literature that best match the most recent WHO systematic reviews 2017-2018.[20] Translating exposure-response functions to a valuation per dB unfortunately fell outside of the scope of this study. However, we recommend that a future, more in depth study into noise costs could attempt to translate the latest WHO exposure-response values into a valuation per dB.

In addition, the noise maps only start measuring at 55 dB, with the first bin representing 55-59 dB. It is likely that the costs presented here are a lower bound estimate if a lower bin of 50-54 dB would be included. This is because it is likely that a large group of the population is exposed to noise within that noise bin.

An issue which builds on this is the fact that the EEA noise maps measure the number of people exposed to certain levels of road, rail and aviation noise. It is possible that a share of the people that are exposed to one type of noise (e.g. noise from road traffic), may also be exposed to other types of noise (e.g. aviation). Whether there are groups of people that are exposed to more than one noise source is currently unclear. What is further unclear is whether or not the valuations for noise are still valid when there are multiple sources at work. In this study we have implicitly assumed that people are only exposed to one source of noise. However, if future studies reveal that a percentage of people are exposed to more than one noise source, further research should be conducted on whether or not the valuations for the different noise sources can simply be added together.

As for specific country values, the following are worth noting. For Greece, the number of people exposed to road noise are not included in the noise maps. Therefore, EU28 average values were used as a proxy for average noise costs in Greece. To calculate the total noise costs, the average values were multiplied with the transport performance data for Greece. Although this is unlikely to significantly affect the EU28 noise costs, it is an important note of caution to keep in mind when looking at the specific Greek situation. More research could be conducted to achieve road noise exposure data for Greece.

For aviation there was noise exposure data missing for Zagreb Plesno Airport and Ljubljana Brink Airport. To calculate the noise costs for these airports, an average of eastern European airports (Prague, Budapest, Warsaw, Bucharest, Riga, Sofia, Vilnius, Tallinn and Bratislava) was first calculated. This was preferred to a selected EU airport average as there are some airports (e.g. Heathrow and Luxembourg) that have notoriously high noise costs, significantly affecting the average. The eastern European average noise cost was then multiplied with the transport performance data on aviation to calculate the total noise costs for the airports in Zagreb and Ljubljana.

[20] Please note that this is also the approach used for other cost categories.

7 Congestion costs

7.1 Introduction

Congestion is defined as a condition where vehicles are delayed when travelling.
In particular, a congestion cost arises when an additional vehicle reduces the speed of the other vehicles of the flow and hence increases their travel time. Road congestion cost can be defined on the basis of a speed-flow relationship in a given context[21], for example at an urban or inter-urban level. This approach cannot be expanded to other transport modes, like rail and air, as they essentially provide scheduled services and are planned on the basis of the allocative capacity of networks and nodes.

It is worth remarking that the road congestion costs presented in the following sections are outputs of a model designed to estimate the overall magnitude of this externality at EU-wide level and from which we derive representative average and marginal cost figures at national level. Because of the high-level scale of analysis of the model used to carry out the estimations (which for example does not incorporate network effects due to the application of pricing policies), it is recommended to develop specific models for context-specific evaluations.

This chapter has been organised as follows. In Section 7.2 we first briefly discuss the definition and scope of congestion costs with respect to road and other transport modes. The total and average road congestion costs are presented in Section 7.3 and the social marginal congestion cost is the topic of Section 7.4. The robustness of the road congestion cost figures presented in this chapter is analysed in Section 7.4.4. More detailed information on road congestion costs can be found in Annex F.

It is important to note that road congestion can also have impacts on other externalities. For instance, a variation of the level road of congestion implies a variation of the emissions of pollutants (local and global) and road accidents, and therefore of their external costs. These costs are handled where possible in the other chapters of the Handbook.

7.2 Definition and scope

A variety of definitions of road congestion exist (Grant-Muller & Laird, 2007). From the objective perspective we assumed, road congestion can be defined as the impedance that vehicles impose on each other, as the traffic flow approaches the maximum capacity of the network (adapted from (Goodwin, 2004)).

As far as the other transport modes are concerned, the approach to estimate the external costs needs to be different because for scheduled services the congestion cost should, in principle, not be an issue until a perturbation occurs and propagates through the system.

[21] Road congestion can be defined also on the basis of a bottleneck model, but it cannot be generalised as the free-flow model to produce countrywide and Europe-wide results.

7.2.1 Road congestion costs

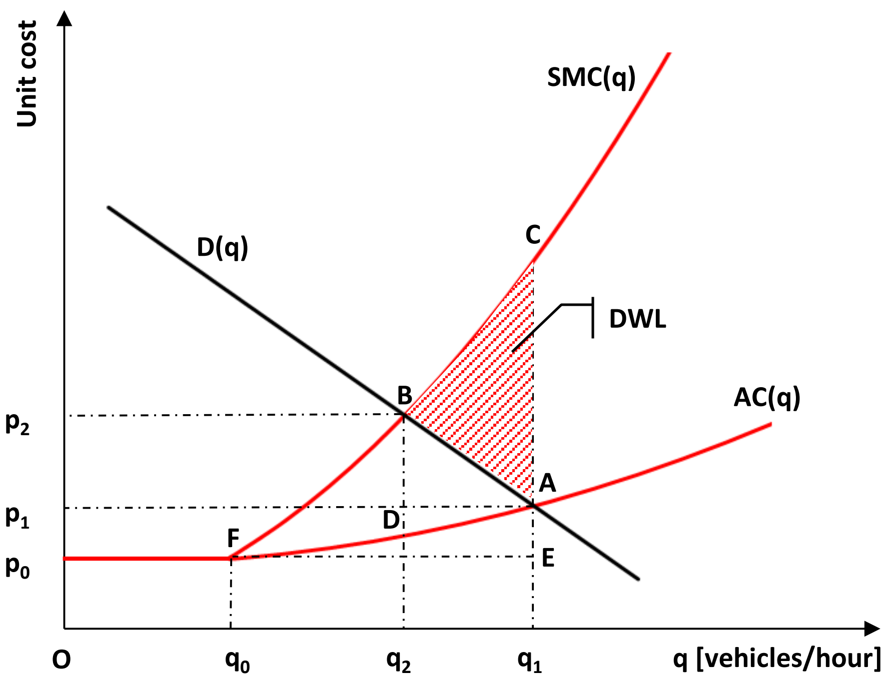
With respect to the road mode, the relationship between speed and flow is to be interpreted as follows. Until the flow is significantly lower than the capacity of a link, the vehicles can travel at free-flow speed. As the flow increases, the speed gradually decreases.

The average travel cost borne by the road users is based on the product of the value of time, which can be assumed constant across road users, and the average travel time.

Basically, there are two approaches to estimate road congestion costs, namely the delay cost and the deadweight loss.

In Figure 7, the cost of travel is equal to p_0 until the free-flow condition holds. When the flow increases, the speed reduces, the travel time increases, and consequently the average travel cost borne by the road users increases according to the shape of the private cost function$AC(q)$, until it intersects the demand curve of usage of the road link$D(q)$.

Figure 7 - Road congestion depending on network conditions



The delay cost approach defines the road congestion cost as the value of the travel time lost relative to a free-flow situation. In Figure 7, the delay cost coincides with the rectangle p_0EAp_1.

The function $SMC(q)$ represents the social marginal cost function, which is equal to the average travel cost borne by the road users $AC(q)$ plus the cost of the additional travel time, generated by the marginal vehicle that reduces the speed of all the other vehicles.

The deadweight loss approach enables to determine the economically optimal solution (i.e., the point B where the demand function and the social marginal cost function intersect). According to this approach, the external cost of congestion is given by the demand in excess with respect to q_2 and the triangle ABC is the so-called 'deadweight loss' (i.e., DWL). The road congestion cost defined in this manner is regarded as a proper basis for transport pricing. At the same time, the delay cost reflects the total congestion cost, in a way which is (partly) comparabale to the total external cost for the other cost categories[22]. For this reason both approaches are applied and presented in this Handbook. For a more detailed discussion on the theoretical background of road congestion we refer to Annex F.

The calculations of delay cost and deadweight loss enables us to estimate the total external road congestion costs of the contexts considered[23]. The average cost can be obtained dividing the total cost estimated by the vkm of that context. The marginal cost is given by the cost due to the additional vehicle that enters the flow and coincides with the segment AC in Figure 7.

7.2.2 Approaches to external congestion cost of other transport modes

For scheduled modes only, the probability that a cost arises increases with an increase of slots. The external cost depends on the capacity and it can be identified according to two categories, namely congestion costs and scarcity costs.

- A 'congestion cost' arises when one scheduled service delays another. Although the timetables will be designed to prevent this from happening, it could be the case that at high levels of utilisation, the presence of an additional scheduled service may lead to an additional delay to others (i.e., 'reactionary delay').

- A 'scarcity cost' arises where the presence of a scheduled service prevents another scheduled service from operating, or requires it to take an inferior slot. Therefore, scarcity costs are incurred whenever a slot is reserved. In essence, scarcity costs denote the opportunity cost to service providers for the non-availability of desired departure or arrival times.

It is worth observing that this kind of analysis needs a large amount of information (e.g., traffic density, mix of scheduled trains, reliability rate and average delay, etc.), as well as complex elaborations. The necessary estimations are highly context-specific and therefore very sensitive for traffic situations. This is an aspect that deserves due consideration, as it significantly limits the opportunities for generalising estimations[24].

22 The delay costs include both internal (costs borne by the same transport user who cause them) and external delay costs. This should be considered when comparing the delay costs with the total/average costs of other externalities.

23 It is worth reminding that the DWL implies a different approach with respect to the delay cost and the methodology to estimate the other external costs. This depends on the nature of road congestion, as the cost of congestion depends on marginal vehicle that enters the traffic and this situation can be represented only by the DWL approach.

24 As an example, for 2018, preliminary results by EUROCONTROL estimates a total costs for delays in the ECAC countries at 14.5 billion €. Such costs are caused not only by air traffic control staff shortages and capacity issues but are also due to strikes, bad weather and technical problems.

7.3 Total and average road congestion costs

The total yearly road congestion costs per country can be calculated for both delay cost and deadweight loss approaches developing a bottom-up approach and building on the values of delay cost per vkm and deadweight loss per vkm estimated for representative types of circumstances on a congested network. These representative circumstances reflect different road types (i.e., urban roads, urban trunk roads, inter-urban roads and motorways) and different levels of capacity occupancy (i.e., near capacity, congested and over capacity). The values obtained have to be combined with additional input values related to real traffic data as well as transport modelling and statistics on mobility in order to estimate total road congestion costs.

In the following paragraph the methodology for the calculation of total and average road congestion costs is explained, including the input and output values.

7.3.1 Methodology

The estimation of total road congestion costs, according to delay cost and deadweight loss approaches, needs to be distinguished with respect to urban and inter-urban contexts. The main reason is that the available information regarding the observed delay generated by traffic is of a different nature. For the urban context, the available information consists of congestion indexes and amounts of time losses for a sample of cities. For the inter-urban context, the available information consists of the amount of delay for a large number of spots localised on the European road network.

Road urban congestion costs

The methodology for the estimation of total cost of urban congestion can build on aggregate congestion indexes by city. The information needs to be provided with respect to the level of congestion, the road network length by road type (i.e., trunk urban road, other urban road), the average delay per day and the total accumulated delay per year.

Building on the information above, the amount of congested network by road type and time period can be estimated. Then, this information can be used together with the values of deadweight loss per vkm and delay cost per vkm (differentiated by time period and road type) to estimate the congestion cost per vehicle. Finally, in order to expand the result to the whole city on a yearly basis, total yearly costs in each urban context can be estimated by using the population size, the share of individuals travelling and the car share, assuming 230 work days per year[25].

Based on these results, the costs estimated on the sample of cities can be applied country by country (e.g., to the cities with at least 50,000 inhabitants)[26].
Figure 8 illustrates the methodology for estimating urban congestion costs.

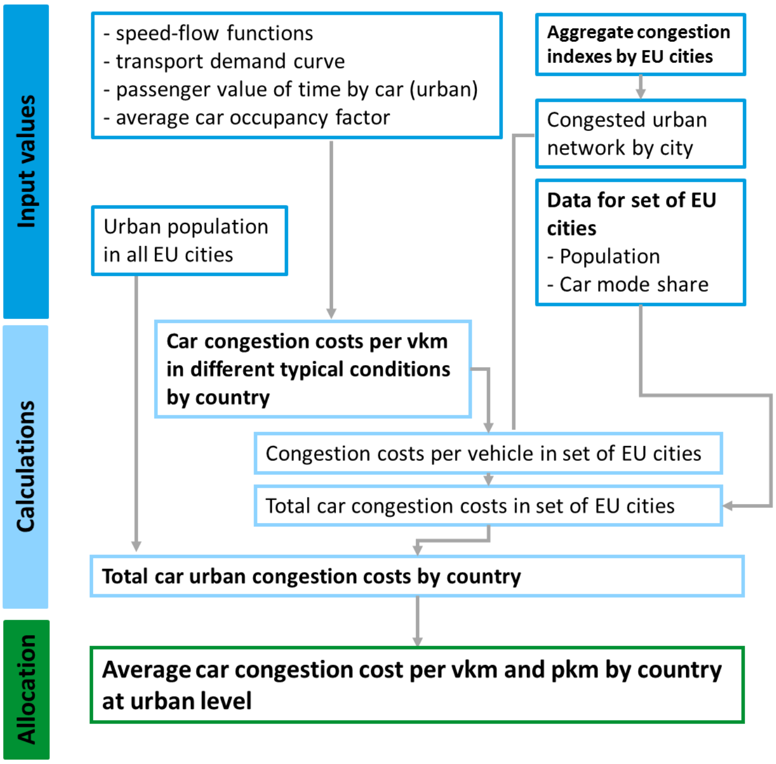
[25] The set of costs obtained for an available sample of cities at country level can also be used for statistical analyses aimed at identifying correlations between the congestion cost (e.g., cost per capita) and some known features of the cities such as population size.

[26] A simplified approach could be adopted to generalise urban congestion costs also to cities below the assumed threshold, taking into account the population in the NUTS3 zone and the typology of NUTS3 according of the classification urban/mixed/rural.

The estimation of **average car congestion cost per vkm** (pkm or tkm) at urban level is performed as a ratio between the total congestion cost and the total vkm (pkm or tkm) on the whole urban road network (not only the congested roads).

With reference to congestion costs for freight vehicles (i.e., HGV and LCV) at the urban level, the methodology applied for cars could not be replicated, due to lack of information. Therefore, in order to provide some information to also cover this aspect, a simplified approach has been applied, based on the estimation of congestion costs for cars, the Value of Time by road vehicle category and data on vkm at urban level for LCVs and HGVs (estimated/collected within this Handbook).

Figure 8 - Methodology for estimating urban congestion costs for delay cost and deadweight loss approaches



Road inter-urban congestion costs

The quantification of traffic experiencing congestion on inter-urban roads can be estimated building on two main sources. First, identifying congested spots on the inter-urban road network, namely the spots where road traffic is delayed in the most congested peak hour[27]. Second, by means of parameters derived from the characteristics of the road network.

Assuming ranges of delays for the congested spots and the speed-flow function of the roads where the spots are located, one can estimate the level of occupancy of each spot at peak times, i.e. the amount of vehicles experiencing congestion in the most congested peak hours (i.e., in terms of Passenger Cars Equivalents, or PCEs). On the basis of daily traffic profiles assumed, the load in each hour can be estimated for different classes of road users

[27] For each spot, the amount of delay could be expressed in terms of additional time per km.

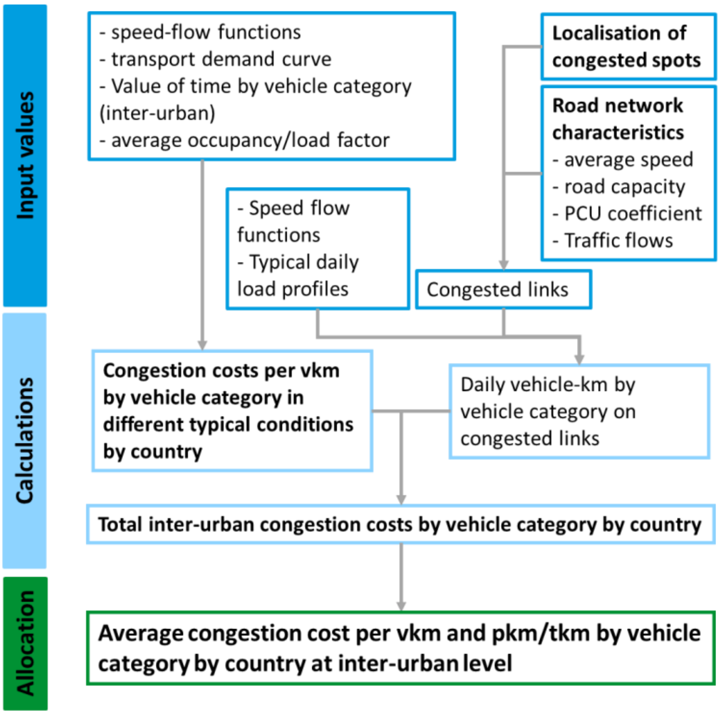
(e.g., cars, trucks and coaches). The share of demand belonging to each class can be estimated assuming a traffic segmentation (if available, from observations or modelling exercises) (see Box in Annex F)[28].

Given the capacity of the road links and considering the sum of all vehicle types (in terms of PCEs), the load/capacity ratios can be estimated for each road link and hour (i.e., near capacity, congested or over capacity[29])[30].

After this process, the total number of vehicles incurring congestion on the inter-urban network in an average day is obtained for the assumed classes of road users. Vkms in congestion by vehicle type can be estimated by multiplying loads by length of congested network on a link level. The estimation of the amount of yearly traffic can be made assuming 230 workdays per year.

The estimation of **average congestion cost per vkm** (pkm or tkm) by vehicle category at inter-urban level is performed as a ratio between the total congestion cost and the total vkm (pkm or tkm) on the whole inter-urban road network (not only the congested roads). With reference to congestion costs for LCVs at inter-urban level, a simplified approach has been applied in order to provide some information to also cover this aspect. Figure 9 illustrates the methodology for estimating inter-urban congestion costs.

Figure 9 – Methodology for estimating inter-urban congestion costs for delay cost and deadweight loss approaches



28 See also TRansport eUropean Simulation Tool

29 The following assumptions have been applied. Near capacity: flow to capacity ratio between 0.8 and 1.0. Congested: flow to capacity ratio between 1 and 1.2. Over capacity: flow to capacity ratio above 1.2.

30 For example, all vehicles travelling in hours with a load/capacity ratio higher than 0.75 can be considered experiencing congestion.

7.3.2 Input values

To estimate urban and inter-urban road congestion costs the following common input values are needed:

- **Speed-flow functions.**

- **Demand curve** $D(q)$ based on literature cost elasticity. In particular, Littman (2011) and Oum et.al. (1990) suggest different elasticity parameters to construct the demand curve. They have been used by vehicle category and for peak and off-peak periods. For cars, values have been estimated as weighted average of values by trip purpose, considering the composition of trips in different periods.

  Value of time (VOT) for car and coach passengers by purpose (i.e., commuting, business and leisure), for the drivers of the different vehicles and for freight road transport (commodity). Values are needed by country and for short/long distance trips. This Handbook uses UK Department for Transport (ARUP, 2015) for passengers and HEATCO (2006), Comité National Routier (2016), Significance, VU University Amsterdam, John Bates Services (2012) for freight. For freight transport (i.e. HGV and LCV) and coaches the VOT of the driver has been considered in the analysis. The values can be found in Annex F.2.2.
- Average **vehicle occupancy/load factors** for cars, buses, coaches, LCVs and HGVs are those estimated within this Handbook by country.

With reference to the estimation of **urban road congestion cost**, specific inputs needed are:

- **Data on the level of congestion and road network length** by road type (i.e., trunk urban road, other urban road), average delay per day and total accumulated delay per year (related to peak period journeys). Available from TomTom for a set of European cities (see TOMTOM Traffic Index).

- **Car mode share in a set of European cities.** The information has been taken from the EPOMM Modal Split Tool (TEMS), integrated with local sources where data from this tool was not available.

- **Population of European cities.** Available from Eurostat and national statistical offices.

- **Typology of NUTS3** according to the degree of urbanisation urban/mixed/rural. The classification is provided by Eurostat.

With reference to the estimation of **inter-urban road congestion cost**, specific inputs needed are:

- **Localisation of the congested spots on the European inter-urban road network.** Provided by the Commission's Joint Research Centre, it identifies spots where road traffic is delayed in the most congested peak hour because of traffic and, for each spot, provides the amount of delay (in terms of additional time per km).

- **Road network characteristics** to determine speed-flow functions of the roads where the spots are located in order to estimate the level of occupancy of each spot in peak time, i.e. the amount of vehicles experiencing congestion in the most congested peak hour (i.e., in terms of PCEs[31]). This Handbook assumes the parameters and outputs of the TRUST network model.

- **Daily traffic profiles.** Road profiles describe how traffic changes over a 24-hour period. Representative road load profiles have to be estimated for passenger cars and trucks during the day in different countries.

7.3.3 Output values

This section presents output values for congestion costs. Two types of costs are presented *costs borne* and *costs generated*. *Costs borne* are the costs imposed on the drivers and passengers of the vehicles. *Costs generated* are the costs that the drivers of the vehicles impose on the other traffic participants. In this chapter we first present the *costs borne* (Table 41 and Table 42), and subsequently present the *costs generated* (Table 43 and Table 44). However, in the synthesis chapter we use the *costs generated*, as these are the external costs of a particular vehicle type.

Table 41 summarises the estimations of the total and average congestion costs for road transport, with respect to delay and deadweight loss approaches. The costs in this table are the total costs borne by each vehicle type. It should be underlined that not all vehicle categories have been considered in each context. The congestion costs for coaches has been estimated only at inter-urban level. The impact of cars on public transport is not estimated at urban level. Road traffic induces deviations of public transport from scheduled services (e.g., generating platooning) and this is a context-specific effect, which cannot be estimated at this scale of analysis. The literature does not provide useful evidence to generalise from context-specific applications.

The average congestion cost reported in the table per vkm (pkm or tkm) are estimated on the basis of the traffic on the whole network (not only the congested roads).

[31] PCE coefficients are taken from the TRUST model parameters, i.e. equal to 1 for cars and 2 for HGVs. For coaches it is assumed the same value as HGVs.

Table 41 - Total and average congestion costs borne by road vehicle categories in the EU28

Vehicle category	Delay costs			Deadweight loss costs		
Passenger transport	**Total EU28 [Billion €]**	**€-cent/ pkm**	**€-cent/vkm**	**Total EU28 [Billion €]**	**€-cent/ pkm**	**€-cent/vkm**
Passenger car	206.2	4.37	7.03	35.6	0.75	1.21
Passenger car - urban	172.6	11.82	19.03	30.0	2.06	3.31
Passenger car - inter-urban	33.6	1.03	1.66	5.5	0.17	0.27
Coach *inter-urban* *	2.1	0.74	14.49	0.2	0.08	1.50
Total passenger	**208.3**			**35.8**		
Freight transport	**Total EU28 [Billion €]**	**€-cent/ tkm**	**€-cent/vkm**	**Total EU28 [Billion €]**	**€-cent/ tkm**	**€-cent/vkm**
Light commercial vehicle	38.5	11.63	8.05	6.6	2.01	1.39
*LCV - urban***	32.6	27.75	19.21	5.6	4.78	3.31
*LCV - inter-urban***	5.9	2.78	1.92	1.0	0.48	0.33
Heavy Goods Vehicle (HGV)	23.8	1.30	17.72	3.8	0.21	2.81
*HGV - urban***	17.6	3.81	51.94	3.1	0.67	9.11
HGV - inter-urban	6.2	0.45	6.20	0.7	0.05	0.69
Total freight	**62.3**			**10.4**		
Total road transport	**270.6**			**46.2**		

* Only inter-urban congestion considered for coaches.

** Simplified approach based on estimation for cars.

Table 42 summarises the estimated total congestion costs related to inter-urban traffic on the motorways network only that is borne by the vehicles.

Table 42 - Total and average congestion cost of inter-urban traffic borne by vehicle categories on motorways network

Vehicle category	Delay costs			Deadweight loss costs		
Passenger transport	**Total EU28 [Billion €]**	**€-cent/pkm**	**€-cent/vkm**	**Total EU28 [Billion €]**	**€-cent/pkm**	**€-cent/vkm**
Passenger car - *inter-urban*	2.91	0.27	0.43	0.67	0.06	0.10
Coach - *inter-urban*	0.20	0.15	2.87	0.03	0.02	0.49
Total passenger	**3.11**			**0.70**		
Freight transport	**Total EU28 [Billion €]**	**€-cent/tkm**	**€-cent/vkm**	**Total EU28 [Billion €]**	**€-cent/tkm**	**€-cent/vkm**
LCV - *inter-urban***	0.50	0.69	0.48	0.12	0.17	0.12
HGV - *inter-urban*	1.09	0.19	2.55	0.19	0.03	0.46
Total freight	**1.59**			**0.31**		
Total road transport	**4.70**			**1.01**		

** Simplified approach based on estimation for cars.

In order to provide an estimation of the external road congestion costs based on the vehicle categories generating congestion, a further step has been made. The total congestion costs of passenger car, by country and by context, have been distributed amongst the other road vehicle categories a measure representative of the share each vehicle type has in the cause of congestion. In principle, the measure should be related to the traffic composition in a congested situation, but this information is not readily available and strictly depends on specific context and time of the day. Therefore, a simplified approach has been developed by assuming that this measure could be obtained multiplying the total vkms of a given context by the Passenger Car Equivalent coefficient (PCEs) of each vehicle type[32].

The average generated congestion costs per vkm (pkm or tkm) are then estimated as ratio between the total costs and the traffic on the related total network (not only the congested roads).

The following table summarises the estimated total and average congestion costs generated by road vehicle categories in the EU28, according to the simplified approach used.

Table 43 - Total and average congestion costs generated by road vehicle categories in the EU28 according to the simplified approach used

Vehicle category	**Delay costs**			**Deadweight loss costs**		
Passenger transport	**Total EU28 [Billion €]**	**€-cent/ pkm**	**€-cent/vkm**	**Total EU28 [Billion €]**	**€-cent/ pkm**	**€-cent/vkm**
Passenger car	196.1	4.2	6.7	33.5	0.7	1.1
Urban	160.8	11.0	17.7	28.0	1.9	3.1
Inter-urban	35.3	1.1	1.7	5.5	0.2	0.3
Bus/ Coach	4.5	0.8	15.9	0.8	0.1	2.7
Urban	3.9	1.8	35.5	0.7	0.3	6.1
Inter-urban	0.5	0.2	3.1	0.1	0.0	0.5
Total passenger	**200.6**			**34.3**		
Freight transport	**Total EU28 [Billion €]**	**€-cent/ tkm**	**€-cent/vkm**	**Total EU28 [Billion €]**	**€-cent/ tkm**	**€-cent/vkm**
Light commercial vehicle	55.5	16.8	11.6	9.4	2.8	2.0
Urban	46.5	39.6	27.4	8.0	6.8	4.7
Inter-urban	9.0	4.2	2.9	1.4	0.7	0.5
Heavy Goods Vehicle (HGV)	14.6	0.8	10.9	2.5	0.1	1.8
Urban	11.6	2.5	34.1	2.0	0.4	6.0
Inter-urban	3.0	0.2	3.0	0.5	0.0	0.5
Total freight	**70.1**			**11.9**		
Total road transport	**270.7**			**46.2**		

[32] The following assumptions have been made for PCE coefficients (taken where available from the TRUST model parameters): equal to 1 for cars, 2 for HGVs and bus/coaches, 1.5 for LCVs.

Table 44 - Total and average congestion cost generated of inter-urban traffic by vehicle categories on motorways network, according to the simplified approach used

Vehicle category	Delay costs			Deadweight loss costs		
Passenger transport	**Total EU28 [Billion €]**	**€-cent/ pkm**	**€-cent/vkm**	**Total EU28 [Billion €]**	**€-cent/ pkm**	**€-cent/vkm**
Passenger car - inter-urban	3.2	0.28	0.45	0.7	0.06	0.10
Coach - inter-urban	0.1	0.05	0.89	0.02	0.01	0.20
Total passenger	**3.3**			**0.7**		
Freight transport	**Total EU28 [Billion €]**	**€-cent/ tkm**	**€-cent/vkm**	**Total EU28 [Billion €]**	**€-cent/ tkm**	**€-cent/vkm**
LCV - inter-urban	0.9	1.2	0.83	0.2	0.3	0.19
HGV - inter-urban	0.4	0.06	0.88	0.1	0.01	0.20
Total freight	**1.3**			**0.3**		
Total road transport	**4.6**			**1.0**		

7.4 Social marginal road congestion costs

7.4.1 Methodology

The social marginal road costs can be calculated only when the deadweight loss approach is applied, because it needs the estimation of the social marginal cost curve. In this respect, it is worth noting that this is an additional input needed with respect to the delay cost approach, which estimates the road congestion costs only relying on information regarding the private cost curve.

Road congestion (and therefore its cost) is highly dependent on the context. Of course, it is unrealistic to assume that all specific circumstances where congestion occurs can be identified and measured. Therefore, the estimation needs to be developed using representative types of circumstances. These representative circumstances can be reflected in **different road types** (i.e., urban roads, urban trunk roads, inter-urban roads and motorways) and in **different levels of traffic intensity** (i.e., near capacity, congested and over capacity).

The point where the demand curve and private cost curves cross has to be calculated (i.e. point A), as well as the point where the demand curve and the social cost curves cross (i.e. point C). Then the difference between social and private cost curves (i.e. segment AC in Figure 7) can be calculated to obtain the estimation of the social marginal cost[33].
The estimation can be made differentiating peak and off-peak periods to take into account the fact that trip purposes are not the same during different periods of the day and therefore that values of time and elasticities of demand are also variable. As a final step,

[33] This measure is the social marginal cost at the current level of congestion and can be used to estimate the optimal congestion price (i.e., the segment BD in Figure 7). It is also worth observing that the marginal congestion cost can be calculated for a traffic situation, beyond the economically optimal solution, with any congestion charge. In this respect, there are many measures governments can take in the direction to reduce a part of the external cost of road congestion. For example a grant that is introduced to subsidise rail services to shift part of road users to public transport. In this case, the benefit of this reduction in road traffic is the difference between the marginal social cost and the price at the current level of traffic.

the average daily value can be estimated based on an assumption on the amount of trips during peak/off-peak periods.

With regards to this Handbook, for urban roads (i.e., trunk urban road and other urban road) the estimation has been made for passenger cars only, while for inter-urban roads (i.e., motorway, other non-urban roads), the vehicle categories considered are cars, trucks and coaches. The differentiation between vehicle categories mainly consists in different values of demand elasticities and different value of time per vehicle. More details on the methodology to estimate road social marginal congestion costs are provided in Annex F.

It is important to notice that also for the marginal road congestion costs, a differentiation between vehicle types can be made, according to the perspective of the vehicle generating the cost. However, the estimation of the generated marginal road congestion cost by different vehicle types has a limitation, which is related to the calculation of the cost curves.

In general, cost curves depend much on the value of time and the marginal external congestion cost is the difference between private cost function and marginal social cost function (see functions AC and SMC in Figure 7). If the existence of various vehicle types is considered relevant, the calculation of the marginal social cost should consider that the overall transport activity is made of a mix of various vehicle types. The value of time per vehicle is highly variable across vehicle types because of different occupancy (e.g. a car vs. a coach) and because the value of time of passengers and goods is different. Therefore, the curve representing the marginal social costs can only be a sort of average, which will be hardly representative of any real user.

Additionally, another relevant result of the estimation of the marginal road congestion costs is the deadweight loss (area DWL in Figure 7). Of course, for sake of consistency, the estimation of the deadweight loss should be based on the same cost curves used to estimate the marginal social cost. Then, also a demand curve is needed. If the curve of the marginal social cost is a sort of average, also the demand curve should be a sort of average. However, again, different vehicle types have different demand curves because they have different elasticities. So, again, the representativeness of an average demand curve would be limited.

Considering of such complexities, the estimation of marginal generated road congestion costs in abstract terms is an exercise necessarily full of simplifying assumptions. Considering the traffic as a whole, and so using average curves, allows to avoid the introduction of a further element of approximation.

And because of this limitation, the approach developed basically uses a different perspective. It considers who incurs in congestion rather than who generates congestion. This approach allows to take into account differences in values of time (and elasticity of demand). These differences explain why costs are different across vehicle types, even if there is no any reference to the effect of a given type to social costs. Furthermore, this approach does not need to compute ‘average’ cost demand curves representing all different vehicle types, so one level of approximation is avoided.

In the light of this different approach, marginal road congestion costs incurred by a vehicle type cannot be added to other external costs by vehicle type (if not for cars, as for this vehicle type, generated costs are equal to incurred costs).

The social marginal congestion costs presented in Section 7.4.3 have been calculated assuming the perspective of a vehicle incurring in a situation of road congestion. The calculation of the marginal social costs generated has been developed according to the sympilified methodology presented in Section 7.4.4.

7.4.2 Input values

For each road type and capacity occupancy level, the only additional input value needed to estimate the social marginal cost (with respect to the input values already listed in Section 1.3) is the social cost curve $SMC(q)$. It must be calculated as the first derivative of the private cost curve $AC(q)$.

7.4.3 Output values

Values in Table 45 and Table 46 can be used to estimate social marginal congestion costs in specific circumstances if a more detailed analysis is not feasible. The most representative value(s) should be picked up depending on the characteristics of the case under analysis. Traffic situations are identified based on the volume to capacity ratio of a traffic link: it is assumed that 'near capacity' is related to v/c ratios between 0.8 and 1, 'congested' refers to v/c ratios between 1 and 1.2, while 'over capacity' is considered when v/c ratio is above 1.2.

Table 45 - Social marginal congestion costs[34] of road transport per pkm and tkm

Vehicle category	Traffic situation	Urban area		Inter-urban area	
		Trunk roads	Other urban roads	Motorway	Other roads
Passenger transport (€-cent/pkm)					
Passenger car	Over capacity	19.9	41.2	18.2	28.8
	Congested	15.4	36.1	14.1	24.6
	Near capacity	10.8	29.3	9.9	19.4
	Well below capacity	0.0	0.0	0.0	0.0
Coach	Over capacity	n. a.	n. a.	16.3	21.2
	Congested	n. a.	n. a.	12.5	18.1
	Near capacity	n. a.	n. a.	8.8	14.3
	Well below capacity	n. a.	n. a.	0.0	0.0
Freight transport (€-cent/tkm)					
HGV	Over capacity	n. a.	n. a.	9.0	11.7
	Congested	n. a.	n. a.	6.9	10.0
	Near capacity	n. a.	n. a.	4.9	7.9
	Well below capacity	n. a.	n. a.	0.0	0.0

Near capacity: flow to capacity ratio between 0.8 and 1.0.
Congested: flow to capacity ratio between 1.0 and 1.2.
Over capacity: flow to capacity ratio above 1.2.

[34] The Social Marginal congestion cost estimated in this version of the Handbook coincides with the segment AC in Figure 7. This definition has been assumed according to: The Marginal Cost of Traffic Congestion and Road Pricing: Evidence from a Natural Experiment in Beijing (Li, et al., 2016). The Efficient Marginal Congestion Cost (i.e., EMCC) of the 2014 version of the Handbook (see Annex A.1) coincides with the segment BD.

Table 46 - Social marginal congestion costs of road transport per vkm

Vehicle category	Traffic situation	Urban area		Inter-urban area	
		Trunk roads	Other urban roads	Motorway	Other roads
Passenger transport (€-cent/ vkm)					
Passenger car	Over capacity	32.1	66.3	29.4	46.4
	Congested	24.8	58.2	22.6	39.6
	Near capacity	17.4	47.2	15.9	31.2
	Well below capacity	0.0	0.0	0.0	0.0
Coach	Over capacity	n. a.	n. a.	318.5	415.8
	Congested	n. a.	n. a.	245.8	355.0
	Near capacity	n. a.	n. a.	173.0	279.4
	Well below capacity	n. a.	n. a.	0.0	0.0
Freight transport (€-cent/ vkm)					
HGV	Over capacity	n. a.	n. a.	122.0	159.3
	Congested	n. a.	n. a.	94.2	136.0
	Near capacity	n. a.	n. a.	66.3	107.1
	Well below capacity	n. a.	n. a.	0.0	0.0

Near capacity: flow to capacity ratio between 0.8 and 1.0.
Congested: flow to capacity ratio between 1.0 and 1.2.
Over capacity: flow to capacity ratio above 1.2.

7.4.4 Social marginal road congestion cost generated using the simplified approach

In order to provide values of the marginal generated road congestion costs by vehicle type that can be compared to other marginal external costs computed in this version of the Handbook, this section presents an estimation using the same approach adopted in (Maibach et al. (2000) and in the 2008 version of the Handbook, i.e. taking the marginal cost of cars and estimating those of other vehicle types by multiplying this cost by the Passenger Car Equivalent coefficient (PCEs) of each vehicle type.

The following assumptions have been made for PCE coefficients (taken where available from the TRUST model parameters): equal to 1 for cars, 2 for HGVs and bus/coaches, 1.5 for LCVs. Values in Table 47 and Table 48 can be used to estimate social marginal congestion costs generated by different type of vehicles in specific circumstances if a more detailed analysis is not feasible.

Table 47 - Social marginal congestion costs of road transport generated per pkm and tkm using the simplified approach

Vehicle category	Traffic situation	Urban area		Inter-urban area	
		Trunk roads	Other urban roads	Motorway	Other roads
Passenger transport (€ cent/ pkm)					
Passenger car	Over capacity	19.9	41.2	18.2	28.8
	Congested	15.4	36.1	14.1	24.6
	Near capacity	10.8	29.3	9.9	19.4
	Well below capacity	0.0	0.0	0.0	0.0
Bus/Coach	Over capacity	3.3	6.8	3.0	4.7
	Congested	2.5	5.9	2.3	4.0
	Near capacity	1.8	4.8	1.6	3.2
	Well below capacity	0.0	0.0	0.0	0.0
Freight transport (€ cent/ tkm)					
LCV	Over capacity	69.5	143.6	63.6	100.5
	Congested	53.6	126.1	49.1	85.8
	Near capacity	37.8	102.2	34.5	67.5
	Well below capacity	0.0	0.0	0.0	0.0
HGV	Over capacity	4.7	9.7	4.3	6.8
	Congested	3.6	8.5	3.3	5.8
	Near capacity	2.6	6.9	2.3	4.6
	Well below capacity	0.0	0.0	0.0	0.0

Table 48 - Social marginal congestion costs of road transport generated per vkm using the simplified approach

Vehicle category	Traffic situation	Urban area		Inter-urban area	
		Trunk roads	Other urban roads	Motorway	Other roads
Passenger transport (€ cent/ vkm)					
Passenger car	Over capacity	32.1	66.3	29.4	46.4
	Congested	24.8	58.2	22.6	39.6
	Near capacity	17.4	47.2	15.9	31.2
	Well below capacity	0	0	0	0
Bus/Coach	Over capacity	64.2	132.6	58.7	92.7
	Congested	49.5	116.4	45.3	79.2
	Near capacity	34.9	94.4	31.9	62.3
	Well below capacity	0	0	0	0
Freight transport (€ cent/ vkm)					
LCV	Over capacity	48.1	99.4	44.0	69.6
	Congested	37.1	87.3	34.0	59.4
	Near capacity	26.1	70.8	23.9	46.7
	Well below capacity	0	0	0	0
HGV	Over capacity	64.2	132.6	58.7	92.7
	Congested	49.5	116.4	45.3	79.2
	Near capacity	34.9	94.4	31.9	62.3
	Well below capacity	0	0	0	0

7.5 Robustness of results

Due to the fact that road congestion costs are so highly dependent on the methodological approach and specific for local conditions, there is a huge variation in total, average and marginal congestion costs estimations. This large variation conceptually complicates what is meant by road congestion costs, as there is not a unique approach.

For this reason, starting from the previous version of the Handbook, we have developed a methodological approach that enlarges the scope of outputs available to the final user, thus enhancing the potential usability of the outputs for further context-specific applications.
In this respect, total and average road congestion costs, have been estimated for both delay and deadweight loss, in order to present the orders of magnitude at country and EU28 level. The social marginal cost is the measure that can be used to estimate the optimal congestion price.

For the above reasons, we consider the deadweight loss approach more useful for its relevance for policy making and from the perspective of marginal cost pricing. Total and average generated congestion costs have been estimated developing a simplified approach to make them comparable with the other external costs estimated in this Hankbook.

7.6 Congestion costs of other transport modes

The review of existing literature for other transport modes did not reveal many new sources (as compared to the 2014 Handbook) of congestion or scarcity costs estimates, for rail, air or water transport that could be recommended as a best practice methodology (see also Annex F.8).
As illustrated in Section 7.2.2, scarcity costs concern path allocation issues and should be only considered in service planning. They correspond to the opportunity-cost of choosing one of the incompatible services. Since the estimation of scarcity costs is very complex, it has been suggested (see for example Quinet, 2003) to use auctions to reveal the values on which the regulator has an information asymmetry compared to other agents. Once the time table of the services has been designed, congestion costs may happen and they should be taken into account in infrastructure pricing.

For rail some methodologies exist at country level to price rail networks capacity according to type of service, time and path. However, there is no straightforward evidence that the actual charges reflect the scarcity of slots.

The congestion costs of a rail network can be estimated starting from the information on the actual reactionary delays of trains, multiplied by the number of affected passengers and by a suitable average value of time. In the rail industry, there are not many costs borne by the infrastructure manager and operators because of the congestion, excluding the compensation paid to the users for the delays suffered. However, to include these compensations would represent double counting.

Marginal cost estimates for rail freight congestion are available by Christidis and Brons (2016)[35]. The average value for EU is equal to €-cent 43.20 per 1.000 tkm (2016 prices). Table 119 in Annex F.8 shows the values for EU Member States. For US, Austin (2015) estimates rail freight congestion costs to be equal to €-cent 0.0-14.0 per 1.000 tkm (2016 prices).

[35] Freight marginal average external costs of transport per country_v3.xls.

The **urban public transport** congestion costs received little consideration. Prud'homme et al. (2012) argue that, in principle, users shifting from cars to bus, tram or subway, increasing the crowding on urban public transport vehicles, causing a comfort loss to all other passengers already travelling. This comfort loss due to increased crowding from modal shift, which can be considered another form of congestion cost, is an externality leading to a suboptimal usage of the tram, bus or subway[36]. That could be corrected by means of a congestion tax (e.g., subway toll). Prud'homme et al. (2012) elaborated a congestion cost curve for crowding of public transport for the Paris subway on data of 2009. The estimated willingness to pay for a non-congested travel emerged to be equal to € 1.43 per trip. It is also worth noting that, according to de Palma et al. (2017), urban public transport congestion may be as important as road congestion[37]. For example, Borjesson et al. (2017) found that in Stockholm the marginal cost of an extra passenger bus can be higher than the marginal external cost of a car during the peak period. Similar results were found for Paris in Kilani et al. (2014).

For **air transport**, congestion can be associated with a lack of sufficient capacity to accommodate the required demand of aircraft movements for landings and take-offs. Like for rail transport, in airports the airlines do not enter the system randomly, with aircraft movements scheduled in advance (i.e., in time slots). However, any perturbation introduced by exogenous factors causes cascade-effects congestion and accumulation of delays during the next periods.
Congestion costs of airports can be estimated starting from the information on actual delays of flights, observed over a certain time period. That allows us to calculate the total time lost by passengers and airlines to be translated into monetary terms.

For air passengers, once that delay time per flight is available, it is necessary to estimate the number of passengers affected. Ideally, one should have the exact number of passengers on each flight, so that the number of minutes of delays can be translated into total passengers' time[38]. If this is not the case, it is possible to approximate the number of passengers knowing at least the capacity of the aircraft serving a route. If the type of aircraft is known, one can rely on the average number of passengers that each model of aircraft may accommodate. Otherwise, standard values of 60-80% can be taken. The value of time for passengers is generally derived from the literature (e.g., (Wardman, et al., 2012) and if possible this should be differentiated with respect to ticket classes (i.e., first, business and economy).

For airlines congestion involves extra costs because of the degradation of the airline product. First, direct costs that refer to additional fuel consumption, time at gate, taxiing time to enter the runway, en-route flight (e.g., circling) and maintenance. Second, but much more difficult to estimate are the indirect costs borne in terms of lost revenues, compensation to passengers and opportunity costs. Clearly, if passengers' cost of time lost

36 This consideration assumes a short run period approach in which the number of vehicles can be varied, but the infrastructure cannot. If vehicles are added, for example in the peak period to offset the comfort loss, the cost for expanding the vehicles is not an external cost, but an internal cost of the operator.

37 For example, in large metropolitan areas (e.g., Paris and London), there are more trips by public than by private transport.

38 Eurocontrol gathers data that allow delays costs for passengers to be calculated (Eurocontrol, 2017). Eurocontrol publishes data in CODA (i.e., all-causes delay and cancellations to air transport) reports, where delay causes are grouped with respect to primary causes (i.e., airline operations, airport operations, en-route, governmental, weather and miscellaneous.) and reactionary delay. Data refers both to single airports (i.e., ranking the most affected) and pairs of connected airports (i.e., ranking the most delayed links).

has already been considered, the airlines' compensation payments would represent double counting[39].

As far as **inland waterway and maritime transport are concerned**, no illustrative quantification of marginal congestion costs could be identified (see Annex Y for findings from 2008 Handbook, as reported in 2014 version). Regarding scarcity costs for inland navigation, GRACE estimates values between €-cent 38.0 to €-cent 50.0/TEU-km at Kaub and €-cent 65.0 to €1.25/TEU-km at Duisburg. Christidis and Brons (2016) indicate that congestion costs of freight transport for both inland waterways and short sea shipping can be assumed to be negligible for EU Member States.

[39] Passengers cost of delay is a dominating cost for airlines, although generally poorly quantified or supported by incomplete evidence (Cook & Tanner, 2015).

8 Costs of well-to-tank emissions

8.1 Introduction

All cost categories discussed in the chapters before cover direct effects of the transport operation process. However, there is a broad range of other up- and downstream processes directly related to transport that also lead to negative external effects. Taking a life-cycle oriented view on transport, the energy production (well-to-tank), the vehicle and infrastructure production, maintenance and disposal all lead to the emission of air pollutants, greenhouse gases, toxic substances and other negative environmental impacts. The by far most relevant effects are the emissions due to energy production, often also called well-to-tank emissions. These costs are directly linked to the transport activity and can be calculated on a profound basis. Therefore, the present chapter focuses on the costs of well to tank emissions. Any other indirect costs of other up- and downstream processes are covered in Chapter 10 on 'other external costs'.

The cost of well-to-tank emissions (= costs of energy production) includes the production of all different type of energy sources which leads to emissions and other externalities. The extraction of energy sources, the processing (e.g. refining or electricity production), the transport and transmission, the building of energy plants and other infrastructures: all these processes lead to emission of air pollutants, greenhouse gases and other substances. The emissions during the production of energy sources are very relevant in terms of total external costs. Mainly for electricity driven transport modes, the effects of energy production are very relevant since the energy use is virtually emission-free.[40]

8.2 Definition and scope

This chapter focuses the cost related to energy production, i.e. the well-to-tank emissions. The energy production, e.g. electricity production of fossil fuel production, lead to a broad range of negative environmental impacts: emission on air pollutants, greenhouse gases, emission of toxic substances, land use and environmental risks. The present study covers the emission of greenhouse gases (CO_2, CH_4, and N_2O) and air pollutants ($PM_{2.5}$, PM_{10}, NO_x, SO_2, NMVOC) related to all energy production ('precombustion') processes: extraction, processing, transport and transmission. For these effects, there is a well-developed basis for monetization.

Different studies on external costs of transport cover different external cost categories. The most recent studies generally cover the air pollution costs and the climate change costs. Negative impacts on ecosystems, land use or nuclear power risks are not covered for methodological reasons (high uncertainty and monetization not (yet) feasible). Chapter 10 on 'other external costs' further elaborates on some of those topics.

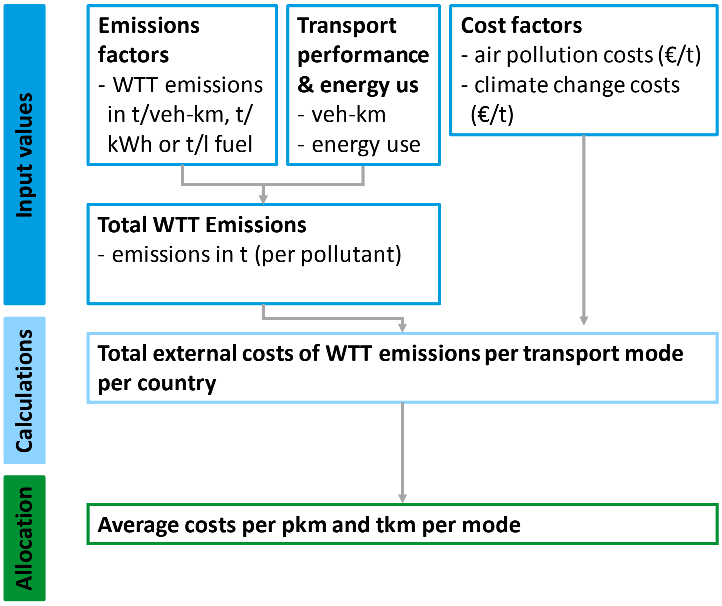
[40] For electric cars, WTT costs are presented in the marginal cost section for selected cases. However, no total and average costs are calculated due to lack of transport performance data.

8.3 Total and average costs of well-to-tank emissions

8.3.1 Methodology

The methodology for calculating the cost of well-to-tank emissions is the same as for the cost of air pollution (see Chapter 4) and the climate change costs (see Chapter 5). The valuation is done with the same cost factors. However, it has to be taken into account that it is very often not known at what place (meaning: at which population density) the emissions occur. Therefore, the valuation has to be made with an average cost factor or a cost factor for 'unknown sources'.

Figure 10 - Methodology total and average costs of well-to-tank emissions



8.3.2 Input values

There are two types of input values for calculating the cost of well-to-tank emissions: The emission factors for the emissions of energy related upstream emissions (i.e. well-to-tank emissions) and the damage cost factors for monetizing the emissions.

The emission factors include the emission of greenhouse gases and air pollutants emitted during the process of energy production. Generally, the average energy consumption (electricity consumption, diesel or petrol consumption) is the central basis for deriving specific emission factors for the well-to-tank emissions.
The main data source for emission factors of well-to-tank emissions are the emission database TREMOD (IFEU, 2017) as well as the European research data from the JEC well-to-wheel analysis (2014). For electric driven vehicles, the emission factors of the country specific electricity mix have been used.

The cost factors for monetizing the emissions are directly taken from the two corresponding cost categories: the air pollution costs (see Chapter 4) and the climate change costs (see Chapter 5). For climate change costs, the same shadow price per tonne of CO_2 is applied. For the air pollution costs, the shadow prices for the emission of air pollutants from unknown sources (EU average) are applied.

Table 49 – Well-to-tank air pollution costs: damage cost estimates in €/kg emission (emissions in the year 2016, EU28 values)

$€_{2016}$/kg	NO_X	NMVOC	SO_2	$PM_{2.5}$ (exhaust)	PM_{10} (non- exhaust)
Austria	21.9	2.3	16.2	26.8	30.9
Belgium	16.2	3.6	17.1	34.6	47.2
Bulgaria	5.7	0	4.2	7.1	5.4
Croatia	12.2	0.9	8	16.3	8.2
Cyprus	5.4	-0.4	7.8	10.9	20.1
Czech Republic	14.5	1.1	11.6	22.6	39.6
Denmark	10.3	1.5	9.6	14	15
Estonia	3.2	0.3	5.2	5.9	4.9
Finland	4	0.4	4.6	4.8	11.9
France	17.3	1.5	13.9	25.1	5.9
Germany	20.2	1.8	16.5	37.7	24.7
Greece	3	0.3	5.9	7.8	24.8
Hungary	15.3	0.8	9.9	20.4	8.5
Ireland	9.8	1.7	11.8	13.7	12.2
Italy	14.1	1.1	12.7	21.1	19
Latvia	4.8	0.4	4.8	5.7	17.2
Lithuania	7.5	0.6	6.4	7.8	27
Luxembourg	35.5	6.2	29.3	63.9	8
Malta	1.7	0.4	4.3	6.2	63.9
Netherlands	14.4	2.8	20.2	37.4	5.6
Poland	8	0.7	8.2	16.3	5.2
Portugal	1.4	0.5	4.1	5.2	47.3
Romania	9.3	0.5	7.3	12.5	16.1
Slovakia	13.8	0.7	10.1	18.4	12.3
Slovenia	13.1	1.2	9.2	16.1	12
Spain	4.9	0.7	6.8	9.9	10.2
Sweden	6.9	0.7	5.5	6.3	15.2
United Kingdom	7.2	1.4	10	18.3	16.2
EU28	10.9	1.2	10.9	19.4	22.3

8.3.3 Output values

Table 50 shows the output values for the well to tank emissions.

Table 50 - Total and average costs of well-to-tank emissions for land-based modes for the EU28

	Total costs EU28	Average costs	
Passenger transport	**Billion €**	**€-cent/pkm**	**€-cent/vkm**
Passenger car	18.13	0.38	0.62
Passenger car - petrol	10.43	0.40	0.64
Passenger car - diesel	7.70	0.37	0.59
Motorcycle	0.83	0.51	0.53
Bus	0.30	0.17	3.12
Coach	0.53	0.15	2.85
Total passenger road	**19.79**		
High speed passenger train	0.33	0.30	90.7
Passenger train electric	2.70*	0.80	106.5
Passenger train diesel	0.07	0.11	6.71
Total passenger rail	**3.10**		
Total passenger transport	**22.90**		
Freight transport	**Billion €**	**€-cent/tkm**	**€-cent/vkm**
LCV	3.79	1.15	0.79
LCV - petrol	0.22	1.18	0.81
LCV - diesel	3.57	1.14	0.79
HGV	3.71	0.20	2.50
Total freight road	**7.50**		
Freight train electric	0.50	0.16	86.5
Freight train diesel	0.13	0.14	61.3
Total freight rail	**0.63**		
Inland Vessel	0.20	0.13	191.4
Total freight transport	**8.33**		
Total road, rail, inland waterway	**31.23**		

* Total costs without highspeed passenger trains (average costs for passenger train electric: incl. high speed trains).

The costs due to greenhouse gas emissions from well-to-tank contribute to about 60-65% of the well-to-tank costs. For road transport, for example, the share of climate change costs is 62%, the share of air pollution costs 38%.

Table 51 - Total and average well-to-tank costs for aviation for 33 selected EU airports

Type of flight	Billion €	€-cent/pkm	€-cent/pax*
Short haul (< 1,500 km)	0.95	1.06	583
Medium haul (1,500-5,000 km)	2.10	0.70	1,276
Long haul (> 5,000 km)	5.83	0.91	7,151
Total	**8.88**	**0.86**	**2,171**

* Costs per pax are including the complete flight (not only the half-way principle). The WTT costs for aviation have been calculated based on specific emission factors for WTT emissions (greenhouse gases and air pollutants) from TREMOD (IFEU 2017).

Table 52 presents rough estimates for the average and total external well-to-tank costs of maritime transport. These data are only available for freight. The average cost have been based on the cost for reference cases presented in Section 8.4 and data on the number of port calls for the selected ports from Eurostat. The total well-to-tank cost has been based on the average cost and the number of tkms provided by DG MOVE[41]. The available data does not allow an estimation of costs at the individual port level.

Table 52 - Rough estimates for total and average external well-to-tank costs for maritime transport for 34 selected EU ports

Transport mode	Total costs (bn €)	Average costs (€-cent/tkm)
Freight ship	4	0.06

8.4 Marginal costs of well-to-tank emissions for selected cases

Like for climate change costs, the marginal costs of well-to-tank emissions, are virtually the same as the average costs.

The costs for road vehicles are presented for all differentiations provided by COPERT, e.g. different fuel types, engines or vehicle sizes, emission classes and regional areas. It needs to be emphasised that, like for climate costs, the Euro standard is not a cost driver. There are some differences between the results for the different Euro standards though, that are the result of the COPERT emission data. These differences are related to the improved energy efficiency over time and impacts of emission reduction technology on fuel efficiency.

The size classes for trucks from COPERT do not match with those for the Eurostat transport performance data used for this Handbook. The load factors for trucks have therefore been based on interpolation of the Eurostat data.

Annex J contains the marginal WTT cost data for road vehicles for reference cases that are defined in terms of the combination of fuel type and fuel efficiency of the vehicle (which are, just like for climate cost, the main cost drivers for WTT cost).

The following table on marginal costs of well-to-tank emissions for road transport shows the costs per pkm or tkm (except for LCV, where costs per vkm are presented due to the fact that LCV have characteristics of freight and passenger transport). The costs per vkm for the different vehicle categories of road transport are available in the background Excel file.

Table 53 - Average/marginal costs of well-to-tank emissions road transport for selected cases

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
Passenger transport (€-cent per pkm)						
Passenger Cars	Petrol	Mini < 0.8 l	Euro 4	0.33	0.32	0.27
			Euro 5	0.33	0.32	0.27
			Euro 6	0.33	0.32	0.27
		Small 0.8-1.4 l	Euro 0	0.47	0.58	0.40
			Euro 1	0.35	0.40	0.31
			Euro 2	0.34	0.39	0.29

[41] See footnote 16.

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro 3	0.34	0.39	0.31
			Euro 4	0.36	0.41	0.32
			Euro 5	0.36	0.41	0.32
			Euro 6	0.36	0.41	0.32
		Medium 1.4-2.0 l	Euro 0	0.58	0.68	0.47
			Euro 1	0.40	0.49	0.36
			Euro 2	0.37	0.47	0.35
			Euro 3	0.41	0.47	0.36
			Euro 4	0.42	0.49	0.38
			Euro 5	0.42	0.49	0.38
			Euro 6	0.42	0.49	0.38
		Large-SUV-Executive > 2.0 l	Euro 0	0.67	0.83	0.57
			Euro 1	0.51	0.63	0.46
			Euro 2	0.51	0.64	0.48
			Euro 3	0.43	0.58	0.42
			Euro 4	0.49	0.71	0.49
			Euro 5	0.50	0.71	0.49
			Euro 6	0.50	0.71	0.49
	Diesel	Mini < 0.8 l	Euro 4	0.18	0.16	0.15
			Euro 5	0.18	0.16	0.15
			Euro 6	0.18	0.16	0.15
		Small 0.8-1.4 l	Euro 0	0.25	0.26	0.20
			Euro 1	0.25	0.26	0.20
			Euro 2	0.25	0.27	0.21
			Euro 3	0.23	0.26	0.21
			Euro 4	0.23	0.26	0.21
			Euro 5	0.23	0.26	0.21
			Euro 6	0.23	0.26	0.21
		Medium 1.4-2.0 l	Euro 0	0.29	0.30	0.24
			Euro 1	0.29	0.30	0.24
			Euro 2	0.29	0.31	0.24
			Euro 3	0.28	0.30	0.24
			Euro 4	0.28	0.30	0.24
			Euro 5	0.28	0.30	0.24
			Euro 6	0.28	0.30	0.24
		Large-SUV-Executive > 2.0 l	Euro 0	0.32	0.35	0.28
			Euro 1	0.32	0.35	0.28
			Euro 2	0.33	0.35	0.28
			Euro 3	0.32	0.35	0.27
			Euro 4	0.32	0.35	0.27
			Euro 5	0.32	0.35	0.27
			Euro 6	0.32	0.35	0.27
	Petrol Hybrid (PHEV)	Mini	Euro 4	0.20	0.15	0.15
		Small	Euro 4	0.20	0.15	0.15
		Large-SUV-Executive	Euro 4	0.20	0.15	0.15
	LPG Bifuel	Small	Euro 1	n.a.	n.a.	n.a.
			Euro 2	n.a.	n.a.	n.a.
			Euro 3	n.a.	n.a.	n.a.

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro 4	0.20	0.22	0.17
			Euro 5	0.19	0.21	0.17
			Euro 6	0.18	0.20	0.16
	CNG Bifuel	Small	Euro 4	0.17	0.19	0.15
			Euro 5	0.17	0.18	0.14
			Euro 6	0.16	0.17	0.14
	Electric (BEV)	n.a.	n.a.	0.83	0.83	0.83
Moped	Petrol	2-stroke < 50 cm³	Euro 0	0.29	0.29	0.29
			Euro 1	0.22	0.22	0.22
			Euro 2	0.22	0.22	0.22
			Euro 3	0.22	0.22	0.22
		4-stroke < 50 cm³	Euro 0	0.29	0.29	0.29
			Euro 1	0.22	0.22	0.22
			Euro 2	0.22	0.22	0.22
			Euro 3	0.22	0.22	0.22
Motorcycle	Petrol	2-stroke > 50 cm³	Euro 0	0.44	0.34	0.32
			Euro 1	0.41	0.31	0.29
			Euro 2	0.40	0.30	0.28
			Euro 3	0.40	0.30	0.28
		4-stroke < 250 cm³	Euro 0	0.47	0.33	0.35
			Euro 1	0.39	0.27	0.29
			Euro 2	0.29	0.24	0.23
			Euro 3	0.29	0.23	0.23
		4-stroke 250-750 cm³	Euro 0	0.51	0.47	0.40
			Euro 1	0.50	0.42	0.38
			Euro 2	0.47	0.38	0.35
			Euro 3	0.46	0.38	0.34
		4-stroke > 750 cm³	Euro 0	0.59	0.54	0.46
			Euro 1	0.51	0.52	0.42
			Euro 2	0.53	0.50	0.41
			Euro 3	0.53	0.50	0.41
	Electric	n.a.	n.a.	0.16	0.16	0.16
Urban buses	Diesel	Midi <=15 t	Euro 0	0.11	0.18	0.11
			Euro I	0.09	0.14	0.09
			Euro II	0.09	0.14	0.09
			Euro III	0.09	0.15	0.09
			Euro IV	0.09	0.13	0.09
			Euro V	0.09	0.13	0.08
			Euro VI	0.09	0.13	0.09
	Diesel	Standard 15-18 t	Euro 0	0.10	0.19	0.11
			Euro I	0.09	0.15	0.09
			Euro II	0.09	0.15	0.09
			Euro III	0.09	0.16	0.10
			Euro IV	0.09	0.14	0.10
			Euro V	0.08	0.14	0.09
			Euro VI	0.09	0.14	0.09
	Diesel	Articulated > 18 t	Euro 0	0.10	0.19	0.11
			Euro I	0.09	0.16	0.10

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro II	0.09	0.16	0.10
			Euro III	0.09	0.16	0.10
			Euro IV	0.09	0.15	0.10
			Euro V	0.09	0.15	0.09
			Euro VI	0.09	0.15	0.10
	CNG	CNG buses	Euro I	0.21	0.21	0.21
			Euro II	0.19	0.19	0.19
			Euro III	0.16	0.16	0.16
			EEV	0.08	0.14	0.09
	Biodiesel	Biodiesel buses	Euro 0	0.03	0.05	0.03
			Euro I	0.02	0.04	0.02
			Euro II	0.02	0.04	0.02
			Euro III	0.02	0.04	0.03
			Euro IV	0.02	0.04	0.03
			Euro V	0.02	0.04	0.02
			Euro VI	0.02	0.04	0.02
	Electric	Small	n.a.	0.54	0.54	0.54
		Medium	n.a.	0.63	0.63	0.63
		Large	n.a.	0.64	0.64	0.64
Coaches	Diesel	Standard <=18 t	Euro 0	0.09	0.21	0.11
			Euro I	0.09	0.19	0.10
			Euro II	0.09	0.19	0.10
			Euro III	0.09	0.20	0.11
			Euro IV	0.09	0.19	0.11
			Euro V	0.09	0.19	0.10
			Euro VI	0.09	0.19	0.11
	Diesel	Articulated > 18 t	Euro 0	0.08	0.17	0.09
			Euro I	0.07	0.15	0.08
			Euro II	0.07	0.14	0.08
			Euro III	0.07	0.15	0.08
			Euro IV	0.07	0.14	0.08
			Euro V	0.07	0.14	0.08
			Euro VI	0.07	0.15	0.08
Light commercial vehicles (€-cent per vkm)						
Light Commercial Vehicles	Petrol		Euro 0	0.90	1.33	0.81
			Euro 1	0.90	1.33	0.81
			Euro 2	0.89	1.31	0.80
			Euro 3	0.88	1.28	0.78
			Euro 4	0.88	1.27	0.78
			Euro 5	0.55	0.71	0.51
			Euro 6	0.55	0.71	0.51
	Diesel		Euro 0	0.73	0.66	0.49
			Euro 1	0.73	0.66	0.49
			Euro 2	0.73	0.66	0.49
			Euro 3	0.73	0.67	0.49
			Euro 4	0.73	0.67	0.49
			Euro 5	0.60	0.62	0.52
			Euro 6	0.60	0.62	0.52
	Electric		n.a.	3.81	3.81	3.81

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
Freight transport (€-cent per tkm)						
HGV	Diesel	Rigid <=7,5 t	Euro 0	1.05	1.28	1.02
			Euro I	0.97	1.04	0.85
			Euro II	0.94	0.97	0.82
			Euro III	0.99	1.04	0.85
			Euro IV	1.01	0.98	0.86
			Euro V	1.00	0.94	0.83
			Euro VI	1.00	0.96	0.84
		Rigid 7,5-12 t	Euro 0	0.54	0.75	0.54
			Euro I	0.49	0.62	0.48
			Euro II	0.48	0.59	0.46
			Euro III	0.50	0.62	0.48
			Euro IV	0.50	0.59	0.48
			Euro V	0.52	0.59	0.46
			Euro VI	0.52	0.60	0.46
		Rigid 12-14 t	Euro 0	0.31	0.44	0.31
			Euro I	0.28	0.37	0.27
			Euro II	0.27	0.35	0.27
			Euro III	0.28	0.37	0.28
			Euro IV	0.28	0.35	0.27
			Euro V	0.26	0.34	0.27
			Euro VI	0.26	0.35	0.27
		Rigid 14-20 t	Euro 0	0.35	0.56	0.37
			Euro I	0.30	0.45	0.31
			Euro II	0.29	0.42	0.30
			Euro III	0.30	0.45	0.31
			Euro IV	0.29	0.41	0.30
			Euro V	0.27	0.41	0.29
			Euro VI	0.28	0.41	0.30
		Rigid 20-26 t	Euro 0	0.19	0.33	0.21
			Euro I	0.17	0.27	0.18
			Euro II	0.17	0.26	0.18
			Euro III	0.17	0.28	0.18
			Euro IV	0.17	0.26	0.18
			Euro V	0.16	0.26	0.17
			Euro VI	0.16	0.26	0.18
		Rigid 26-28 t	Euro 0	0.14	0.24	0.16
			Euro I	0.13	0.21	0.14
			Euro II	0.12	0.20	0.13
			Euro III	0.13	0.21	0.14
			Euro IV	0.13	0.20	0.14
			Euro V	0.12	0.19	0.13
			Euro VI	0.12	0.20	0.13
		Rigid 28-32 t	Euro 0	0.13	0.22	0.15
			Euro I	0.12	0.19	0.13
			Euro II	0.12	0.19	0.13
			Euro III	0.12	0.19	0.13
			Euro IV	0.12	0.18	0.13
			Euro V	0.12	0.18	0.13

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro VI	0.12	0.18	0.13
		Rigid > 32 t	Euro 0	0.11	0.20	0.13
			Euro I	0.10	0.17	0.11
			Euro II	0.10	0.16	0.11
			Euro III	0.10	0.17	0.11
			Euro IV	0.10	0.16	0.11
			Euro V	0.10	0.16	0.11
			Euro VI	0.10	0.16	0.11
		Articulated 14-20 t	Euro 0	0.19	0.31	0.20
			Euro I	0.16	0.25	0.17
			Euro II	0.16	0.24	0.17
			Euro III	0.16	0.26	0.17
			Euro IV	0.16	0.24	0.17
			Euro V	0.15	0.23	0.16
			Euro VI	0.15	0.24	0.17
		Articulated 20-28 t	Euro 0	0.18	0.31	0.20
			Euro I	0.16	0.28	0.18
			Euro II	0.16	0.26	0.17
			Euro III	0.16	0.27	0.18
			Euro IV	0.16	0.26	0.18
			Euro V	0.16	0.25	0.17
			Euro VI	0.16	0.25	0.17
		Articulated 28-34 t	Euro 0	0.11	0.20	0.13
			Euro I	0.10	0.17	0.11
			Euro II	0.10	0.17	0.11
			Euro III	0.10	0.17	0.11
			Euro IV	0.10	0.16	0.11
			Euro V	0.10	0.16	0.11
			Euro VI	0.10	0.16	0.11
		Articulated 34-40 t	Euro 0	0.11	0.20	0.13
			Euro I	0.10	0.18	0.11
			Euro II	0.10	0.17	0.11
			Euro III	0.10	0.18	0.11
			Euro IV	0.10	0.17	0.11
			Euro V	0.10	0.17	0.11
			Euro VI	0.10	0.17	0.11
		Articulated 40-50 t	Euro 0	0.11	0.19	0.12
			Euro I	0.09	0.17	0.11
			Euro II	0.10	0.17	0.10
			Euro III	0.09	0.17	0.11
			Euro IV	0.09	0.16	0.10
			Euro V	0.09	0.16	0.10
			Euro VI	0.09	0.16	0.10
		Articulated 50-60 t	Euro 0	0.11	0.20	0.13
			Euro I	0.10	0.18	0.11
			Euro II	0.10	0.17	0.11
			Euro III	0.10	0.18	0.11
			Euro IV	0.10	0.17	0.11
			Euro V	0.10	0.17	0.11

Vehicle category	Fuel type	Size	Emission class	Motorway	Urban road	Other road
			Euro VI	0.10	0.17	0.11
	LNG	Articulated 32+	n.a.	0.03	0.05	0.04

Table 54 - Average/marginal costs of well-to-tank emissions rail transport for selected cases

Train type	Traction	€-cent/pkm or €-cent/tkm	€-cent/train-km
Passenger transport			
High-speed train	Electricity	0.39	117.4
Intercity train	Electricity	0.73	117.4
Intercity train	Diesel	0.18	16.1
Regional train	Electricity	0.89	97.9
Regional train	Eiesel	0.26	8.0
Freight transport			
Long container	Electricity	0.11	151.3
Long bulk	Electricity	0.10	156.8
Short container	Electricity	0.26	132.0
Short bulk	Electricity	0.18	135.4
Long container	Diesel	0.03	42.0
Long bulk	Diesel	0.03	43.5
Short container	Diesel	0.07	36.7
Short bulk	Diesel	0.05	37.6

Table 55 - Average/marginal costs of well-to-tank emissions IWT for selected cases (€-cent per tkm)

Vessel type	Type of cargo	€-cent/tkm	€-cent/vkm
CEMT II (350 t)	Bulk	0.15	46.82
	Container	0.09	46.82
CEMT IV (600 t)	Bulk	0.09	69.49
CEMT Va (1,500 t)	Bulk	0.08	126.96
	Container	0.09	126.96
Pushed convoy (11,000 t)	Bulk	0.06	340.02
	Container	0.05	340.02

Table 56 - Average/marginal costs of well-to-tank emissions maritime transport for selected cases

Vessel type	Distance at sea (km)	€ per trip	€-cent per pkm or tkm	€ per vessel-km
Passenger transport				
RoPax Ferry (25,500 gt)	100	2,190	4.15	22
	500	5,513	2.09	11
Small container vessel (28,500 gt)	500	15,437	0.13	31
	3,000	50,891	0.07	17
Large container vessel (143,000 gt)	500	23,338	0.04	47
	3,000	110,190	0.03	37
	15,000	527,084	0.03	35
Small bulk vessel (18,000 gt)	500	4,509	0.06	9
	3,000	19,499	0.04	6
Large bulk vessel (105,000 gt)	500	10,987	0.02	22

Vessel type	Distance at sea (km)	€ per trip	€-cent per pkm or tkm	€ per vessel-km
	3,000	45,149	0.01	15
	15,000	209,129	0.01	14

Table 57 – Average/marginal costs of well-to-tank emissions aviation for selected cases

Type of flight	Distance (km)	Emission class	Example of aircraft type	€-cent per pkm	€ per pax
Short haul	500	Low	Bombardier CRJ900	1.3	6
	500	High	Embraer 190	1.4	7
Medium haul	1,500	Low	Airbus 320	0.5	8
	1,500	High	Boeing 737	0.7	11
	3,000	Low	Airbus 320	0.6	17
	3,000	High	Boeing 737	0.8	24
Long haul	5,000	Low	Airbus 340	0.5	25
	5,000	High	Boeing 777	0.6	28
	15,000	Low	Airbus 340	0.8	121
	15,000	High	Boeing 777	0.9	137

The marginal costs of aviation for selected cases and aircrafts cannot be directly compared with the average costs: The marginal costs refer to very specific aircraft types, distances and loading factors that do not match the average. E.g. for short haul flights, the average number of passenger per flight is substantially higher than for the selected cases (since many short haul flights are done by larger aircraft). Additionally, the average distances are different than the one use in the selected cases.

8.5 Robustness of results

The well-to-tank costs due to the emission of air pollutants and greenhouse gases are quite well investigated. However, the emissions are occurring always indirectly and the exact place of the emissions is generally not known. Therefore, the emission levels always have some uncertainty. The cost factors also have some uncertainty due to the number of people exposed and country where the emissions occur generally being unknown. Overall, the quality of the results for well-to-tank costs is acceptable, but not as high as for the costs due to direct emissions (tank-to-wheel emissions).
A further conceptual consideration is that part of the well-to-tank greenhouse gas emissions will be regulated under the EU Emissions Trading System (EU ETS), which means a carbon price is applied. As the EU ETS is a capped system, reducing well-to-tank emissions does not necessarily lead to equal economy-wide emission reductions in the short term.

9 Costs of habitat damage

9.1 Introduction

Transport has different effects on nature, landscape and natural habitats. The main effects reported in literature are habitat loss (ecosystem loss), habitat fragmentation and negative effects on ecosystems due to the emission of air pollutants (e.g. biodiversity loss). However, the negative effects of transport on nature and landscape are covered in limited external costs studies.

In this chapter, the scope of the cost category is presented (see Section 9.2) and then the total and average costs of nature and landscape are described (see Section 9.3) — first the methodological approach, then the results.

9.2 Definition and scope

The different negative effects of transport on nature and landscape can be described as the following:

- **Habitat loss:** Transport infrastructure requires land and/or natural surfaces. Therefore, transport infrastructure also leads to a loss of natural ecosystems, which are natural habitats of plants and animals. The land use of transport therefore leads to a loss of habitats (ecosystems), which has a negative effect on biodiversity. Habitat loss is occurring during the building phase of transport infrastructure, but will last over the whole lifetime of the infrastructure.
- **Habitat fragmentation:** Transport infrastructure can also have additional fragmentation and separation effects for animals. These fragmentation effects can negatively affect the natural habitats of certain species and lead to adverse effects for species and consequently on biodiversity. Habitat fragmentation due to transport infrastructure is a consequence of the infrastructure itself plus the transport demand on the infrastructure. The main negative effects are caused by large and broad main infrastructures such as motorways and high-speed rail lines. Large wildlife mammals such as deer, rabbit, badger, etc. as well as smaller animals such as amphibians are negatively affected by habitat fragmentation.
- **Habitat degradation due to emissions:** Habitat degradation can also occur via the emission of air pollutants of other toxic substances (e.g. heavy metals, PAH).
  These effects again lead to biodiversity loss and therefore external costs.
  The *biodiversity loss due to air pollution* is already covered in the air pollution chapter (4), where all adverse impacts of air pollution are included. The negative effects of the emission of toxic substances are covered in Chapter 10.

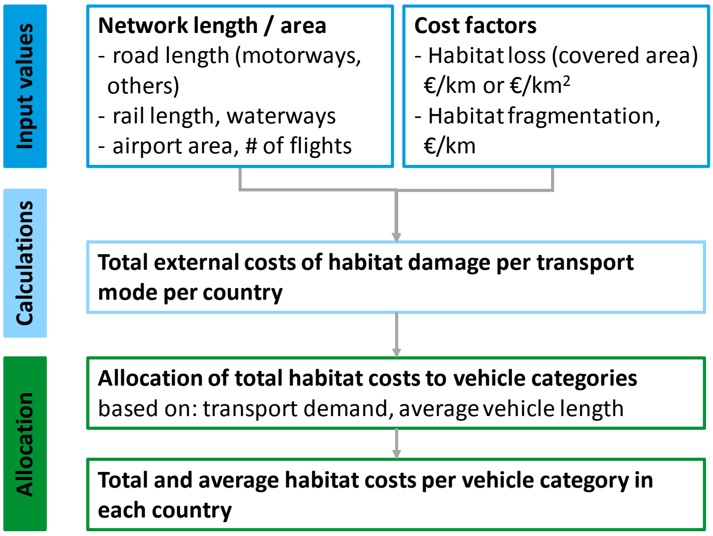
There are limited studies covering the external costs of habitat damage due to transport activities. A brief overview on the relevant literature is shown in Annex G. The most detailed bottom-up calculations of the cost of habitat damage have been made by the European research project NEEDS (2006), INFRAS, Ecoplan (2018) and UBA (2018), based on NEEDS.

9.3 Total and average costs of habitat damage

9.3.1 Methodology

Total and average costs of habitat damage are calculated based on the infrastructure network length (or area) and average cost factors for habitat loss and habitat fragmentation. Figure 6 illustrates the corresponding methodology.

Figure 11 - Methodology total and average costs of habitat damage



9.3.2 Input values

Network length (network area)

The following data sources for transport infrastructure network length (or infrastructure area) are being used:

- Road Transport: EU Transport in Figures.
- Rail Transport: EU Transport in Figures.
- Air Transport: airports (survey); and EU Transport in Figures.
- Inland Waterways: EU Transport in Figures and Eurostat.
- Maritime: ports (survey).

Cost factors

The following table summarizes the cost factors for habitat loss and habitat fragmentation for the EU28 average. The cost factors are derived from the latest bottom-up calculations for the Swiss study on external costs of transport (INF (INFRAS en Ecoplan, 2018).

Table 58 – Cost factors for costs of habitat damage EU28

Cost in €2016 per km and year	Road €/(km *a)		Rail €/(km*a)		Aviation €/(km² *a)	Inland waterways €/(km*a)
	Motorways	Other roads	High-speed	Other railways		
Habitat loss	78,900	1,900	57,500	8,200	437,500	6,600
Habitat fragmentation	14,600	2,200	27,000	5,900	0	0
Total habitat damage	93,500	4,100	84,500	14,100	437,500	6,600

Source: Own calculations based on INFRAS, Ecoplan 2018 (External effects of transport in Switzerland 2015).

Based on the EU28 average values, cost factors for all countries have been calculated (Table 59), based on the same value transfer approach used in the whole Handbook (GDP/cap PPP adjusted).

Table 59 – Cost factors for costs of habitat damage for all countries

Cost in €2016 per km and year	Road €/(km *a)		Rail €/(km*a)		Aviation €/(km² *a)	Inland waterways €/(km*a)
	Motorways	Other roads	High-speed	Other railways		
EU Aggregate (EU28)	93,500	4,100	84,500	14,100	437,500	6,600
Austria	99,700	4,400	90,200	15,000	466,800	7,100
Belgium	93,900	4,100	84,900	14,100	439,200	6,700
Bulgaria	52,900	2,300	47,800	8,000	247,400	3,800
Croatia	56,100	2,500	50,700	8,500	262,700	4,000
Cyprus	69,500	3,100	62,900	10,500	325,500	4,900
Czech Republic	65,400	2,900	59,100	9,900	306,100	4,600
Denmark	125,300	5,500	113,300	18,900	586,500	8,900
Estonia	74,900	3,300	67,800	11,300	350,700	5,300
Finland	125,100	5,500	113,100	18,900	585,500	8,900
France	111,100	4,900	100,500	16,700	520,000	7,900
Germany	120,500	5,300	108,900	18,200	563,800	8,600
Greece	67,500	3,000	61,000	10,200	315,700	4,800
Hungary	55,400	2,400	50,100	8,300	259,100	3,900
Ireland	88,600	3,900	80,100	13,300	414,400	6,300
Italy	74,700	3,300	67,500	11,300	349,400	5,300
Latvia	66,000	2,900	59,600	9,900	308,700	4,700
Lithuania	66,400	2,900	60,000	10,000	310,600	4,700
Luxembourg	98,600	4,300	89,100	14,900	461,400	7,000
Malta	76,900	3,400	69,500	11,600	359,800	5,500
Netherlands	103,000	4,500	93,100	15,500	482,000	7,300
Poland	64,200	2,800	58,100	9,700	300,600	4,600
Portugal	55,000	2,400	49,700	8,300	257,500	3,900
Romania	48,000	2,100	43,400	7,200	224,600	3,400
Slovakia	69,400	3,000	62,700	10,500	324,700	4,900
Slovenia	66,900	2,900	60,500	10,100	313,000	4,800
Spain	72,100	3,200	65,200	10,900	337,400	5,100
Sweden	142,100	6,200	128,500	21,400	665,000	10,100
United Kingdom	99,000	4,300	89,500	14,900	463,400	7,000
Norway	134,500	5,900	121,600	20,300	629,700	9,600
Switzerland	153,900	6,800	139,100	23,200	720,300	10,900

Cost in €2016 per km and year	Road €/(km *a)		Rail €/(km*a)		Aviation €/(km² *a)	Inland waterways €/(km*a)
	Motorways	Other roads	High-speed	Other railways		
Canada	105,300	4,600	95,200	15,900	492,900	7,500
United States	110,200	4,800	99,600	16,600	515,500	7,800
Japan	103,400	4,500	93,400	15,600	483,700	7,300

Source: Own calculations based on INFRAS, Ecoplan 2018 (External effects of transport in Switzerland 2015).

An alternative source for cost factors for habitat loss is the European research study NEEDS (2006), where cost factors for biodiversity loss due to ecosystem (habitat) loss have been reported. The cost factors are based on a restoration cost approach and presented for different ecosystem types.

Table 60 – Cost factors for ecosystem (habitat) loss

Land/ecosystem type	€2015/m²
Built-up land	0
Intensive arable	0
Integrated arable	0.2
Organic arable	0.5
Organic orchards	4.8
Intensive pasture	0.4
Less intensive pasture	0.9
Organic pasture	2.3
Forests	3.2
Forest edge	10.0
Average (all ecosystems)	**1.8**

Source: Own calculations based on NEEDS 2006.

The following results on the external costs of habitat damage have been based on the cost factors presented in Table 58 and Table 59 (based on INFRAS, Ecoplan 2018).

9.3.3 Output values

The following tables show the resulting cost factors (output values) for the cost of habitat damage per vehicle type, based on the cost factors in Table 59 (based on INFRAS, Ecoplan 2018). The tables include the total costs as well as the average costs per vkm and the average costs per pkm and tkm.

Table 61 - Total and average costs of habitat damage for land-based transport modes in the EU28

	Total costs EU28	Average costs	
Passenger transport	**Billion €**	**€-cent per pkm**	**€-cent per vkm**
Passenger car	25.9	0.55	0.9
Passenger car - petrol	*14.1*	*0.54*	*0.9*
Passenger car - diesel	*11.8*	*0.56*	*0.9*
Motorcycle	0.5	0.33	0.3
Bus	0.2	0.10	1.9
Coach	0.4	0.11	2.2
Total passenger road	**27.1**		
High speed passenger train	0.7	0.62	185
Passenger train electric	1.4*	0.57	75
Passenger train diesel	0.5	0.84	49
Total passenger rail	**2.7**		
Total passenger transport	**29.7**		
Freight transport	**Billion €**	**€-cent per tkm**	**€-cent per vkm**
LCV	4.4	1.35	0.9
HGV	3.6	0.19	2.4
Total freight road	**8.0**		
Freight train electric	0.8	0.24	134
Freight train diesel	0.2	0.25	111
Total freight rail	**1.0**		
Inland Vessel	0.3	0.20	2.9
Total freight transport	**9.3**		
Total road, rail & inland waterway	**39.1**		

* Total costs without highspeed passenger trains (average costs for passenger train electric: incl. high speed trains).

Table 62 - Total and average habitat costs for aviation for 33 selected EU airports

Type of flight	Billion €	€-cent/pkm	€-cent/pax
Passenger aviation			
Short haul (< 1,500 km)	0.024	0.027	14.9
Medium haul (1,500-5,000 km)	0.021	0.007	12.3
Long haul (> 5,000 km)	0.005	0.0008	6.5
Total passenger aviation	*0.050*	*0.007*	*12.2*
Freight aviation	**Billion €**	**€-cent/tkm**	
Freight aviation total	0.006	n.a.	

Concerning the marginal costs of habitat damage, the marginal costs of habitat loss are virtually zero (only if infrastructure capacity has to be enhanced due to high demand, there are additional marginal costs). The marginal costs of habitat fragmentation, however, can be assumed to be substantial, and in some cases almost as high as the average cost of habitat fragmentation, since the traffic on a road really hinders animals to pass.
It is not possible to make a generally applicable estimation of the marginal costs of habitat damage. However, the marginal costs will be between zero (as a minimum estimation) and the average costs of habitat fragmentation (as a maximum estimation).

10 Other external costs

The goal of this chapter is to present the further negative externalities of transport. The chapter focuses on other external cost categories that are not quantified or discussed in the previous chapters. Many sub-categories are already mentioned in the previous chapters such as damage costs due to toxic emissions or cost of downstream emissions (see Chapter 8).

This chapter focuses on a qualitative description and brief discussion of other external costs of transport and gives some selective quantitative references. All cost categories with quantitative results and recommendations of cost factors are covered in the detailed chapters above.

10.1 Costs of soil and water pollution

Transport activities lead to certain negative impacts on soil and water:

- Pollution of soil (and water) with **heavy metals**. Different processes lead to the emissions of heavy metals: abrasion of brakes (road, rail), abrasion of tyres and rail track (road, rail), abrasion of the overhead line (rail) as well as the fuel combustion. There are limited studies monetizing the external cost of the emission of heavy metals in transport. In Switzerland, these costs are quantified, but are below 1% of the total external costs of transport. They are most relevant for motorised road transport and rail transport (INFRAS en Ecoplan, 2018). A similar approach has been applied in the last UCI study on external costs of transport in Europe (CE Delft, INFRAS & Fraunhofer ISI, 2011).
- Pollution of soil (and water) with **organic toxic substances.** The burning of fuels also leads to the emission of organic toxic substances (persistent organic pollutants POP). However, the corresponding emissions are relatively low. One of the few studies covering the cost of organic toxic emissions of transport is INFRAS, Ecoplan (2018). In water transport (maritime transport, inland waterways) the use of antifouling agents for ship paint is another source of emissions of toxic substances, generally organic pollutants, metal-organic compounds or heavy metals (e.g. zinc). Specific cost factors for the emission of toxic pollutants such as heavy metals and organic compounds are recommended in the new Dutch Shadow Prices Handbook (CE Delft, 2018) or in the European research study EXIOPOL (2011).
- Pollution of soil (and water) due to **waste and ballast water.** In maritime transport and inland waterways, waste water and ballast water leads to the pollution of seawater, lakes or rivers. The emissions mainly occur in ports and can lead to substantial water pollution. There are several methods for treating ballast and other waste water, which all lead to substantial costs. Hence, the cost of waste and ballast water could be quantified by using a restoration cost approach. The external cost of waste and ballast water are discussed in many studies (e.g. (Hayman, et al., 2000), (Trozzi, 2003) and where quantified (which is rare) this is done by the means of the restoration costs (e.g. (JRC, 2009).
- Pollution of soil (and water) due to **oil spills and oil risks.** A specific type of water pollution is the cost of oil spills or accidents related to the extraction of oil. Such uncontrolled oil emissions lead to substantial pollution of the sea. Above all, the large accidents with oil drillings (e.g. Deepwater Horizon) have led to high environmental costs. Many studies mention those effects and give indicative data on the external costs (e.g. (Navrud, et al., 2016); (Farrow & Larson, 2012); (Bigano, et al., 2009); (VTPI,

2017). Those cost factors are however mainly from single events or accidents or refer to the costs of preventative measures (Navrud, et al., 2016).

10.2 Costs of up- and downstream emissions of vehicles and infrastructure

The upstream costs of energy production are covered in Chapter 8. However, there are different other up- and downstream processes directly related to transport that also lead to negative external effects. Taking a life-cycle oriented view on transport, the following processes lead to the emission of air pollutants, greenhouse gases, toxic substances and other negative environmental impacts:

- **Vehicles:** An important input factor for transport are the vehicles (e.g. cars, trucks, planes, rolling stock, etc.). The production, maintenance and disposal of vehicles causes the emission of air pollutants, greenhouse gases and other pollutants. Hence, during the whole life cycle of the vehicles, negative environmental impacts occur.
- **Infrastructure:** Similar to vehicles, transport infrastructure also leads to negative environmental effects during its life cycle. Emission of greenhouse gases, air pollutants and other substances are caused by the construction, maintenance and disposal of transport infrastructures.
- **Energy production (other effects):** The energy production (fossil fuels, electricity) do not only lead to the emission of air pollutants and greenhouse gases (covered in Chapter 8), but also to ecosystem damage and loss. For example, electricity production by wind power stations, hydroelectric plants or large solar energy plants can cause substantial ecosystem damage.

The life-cycle emissions of air pollutants and greenhouse gases for vehicles and infrastructure are covered in a number of external cost studies (e.g. (UBA, 2018), (CE Delft, INFRAS & Fraunhofer ISI, 2011), (INFRAS en Ecoplan, 2018)) . However, the ecosystem damage due to energy production is covered only in selected studies, generally focussing on very concrete cases and ecosystems (e.g. based on a willingness-to-pay study). Generalised cost factors or shadow prices for ecosystem damage due to wind, solar or hydro plants are not available yet.

10.3 External costs in sensitive areas (e.g. mountainous regions)

Different studies have proved that certain types of external costs are higher in sensitive areas, such as mountain areas, than in non-sensitive areas. An important study analysing these impacts was the European research study GRACE (2006), which identified so called mountain-factors describing the differences in external costs between mountain areas and non-mountain areas. As a result, the Eurovignette directive allows mark-ups to HGV tolls in sensitive areas.

Recently, two studies have validated and updated the mountain factors, based on the methodological approach of the GRACE (2006) study (EUSALP, 2017), (CEREMA, 2018). In the study from EUSALP (2017), all cost drivers that influence the different environmental costs are reassessed, considering the latest research results. Additionally, possible additional cost drivers are examined as well as additional cost categories (accident costs, costs for nature and landscape). Finally, new mountain factors for Alpine regions have been suggested.
The following section summarises briefly the methodology and results from the EUSALP (2017) study.

The analysis to derive cost factors (mountain factors) follows the approach along the 'impact pathway approach', as the main methodology to assess environmental costs based on a damage cost approach. The methodological approach used in the present study is the same as in the GRACE study (2006), which is based on cost drivers and 'cost differential factors' (mountain factors) along the impact-pathway. The following elements of the impact-pathway can influence the external costs in mountain regions:
- Emissions: higher emission level e.g. due to gradients and altitude.
- Concentration: higher concentration of air pollutants e.g. due to topographical and meteorological conditions.
- Impacts: different impacts based on the dose(concentration)-response evidence, e.g. due to other population density or other risk factors.
- Damage cost: different cost factors for damage costs, i.e. due to country-specific monetization factors, specific prices, etc.

In summary, the mountain factors for all levels of the impact-pathway approach result in an overall factor for the cost per transport performance (vkm) in mountain regions in comparison to non-mountain regions (or a country average). The result of the analysis is a 'mountain factor' for a certain category of external costs (e.g. air pollution costs, noise costs, accident costs) and transport mode (road, rail).

The EUSALP (2017) study analysed the following cost categories: air pollution costs, noise costs, nature and landscape costs (habitat damage), accident costs and climate change costs. The EUSALP study focuses on rail and road freight transport. The analysis is based on a corridor approach, meaning that the cost factors derived apply to whole corridors and not only specific infrastructures.

The following table summarises the main results of the EUSALP (2017) study, showing the mountain factors for the different external cost categories. Additionally, the values of the GRACE study (2006) are also represented as a comparison. It is important to state that the different mountain factors do not say anything about the absolute level of external costs, but only represent the factors between external costs in mountainous and external costs in non-mountainous areas.

Table 63 - Mountain factors for external costs of freight transport

Cost category	EUSALP (2017)		GRACE (2006)	
	Road transport	Rail transport	Road transport	Rail transport
Air pollution	4.2	2.6	5.25	3.5
Noise	4.1	3.0	5.0	4.15
Nature & landscape	1.3	1.4	*n.a.**	*n.a.**
Accidents	3.9	*n.a.*	*n.a.*	*n.a.*

Source: EUSALP (2017). n.a.: not available/no data available.

* For visual intrusion, the GRACE study suggested a factor of 10.7 for road transport and 5.3 for rail transport.

The results of the analysis of external costs of transport in mountain areas can be summarised as following (cited from EUSALP 2017):
- **Air pollution costs:** The main cost driver for the air pollution costs in the Alpine Region are the higher immissions due to inversion (factor 4.4). Other cost drivers are the higher emissions due to the higher gradients and the altitude (e.g. higher emissions due to steeper roads/rails and higher exhaust emissions in higher altitudes). The resulting mountain factor for air pollution is slightly lower than in the GRACE (2006) study, which is mainly as a result of the lower factor for population density (based on a more

detailed GIS based analysis), which outweighs the slightly higher value for the immission (concentration). However, overall the air pollution costs in mountain areas are substantially higher than in non-mountain areas.
- **Noise costs:** For noise costs, the main cost driver in mountain areas are the higher immissions due to topographical and meteorological conditions (inversion, amphitheatre effect). Other relevant factors are the gradients (higher noise emissions due to steeper roads/rails) and the population density. The resulting mountain factor for noise costs are slightly lower than in the GRACE (2006) study (again mainly as a result of the lower factor for population density).
- **Costs of habitat damage (nature and landscape):** For nature and landscape, a mountain factor has been derived for the first time in the EUSALP (2017) study. Based on detailed results of the Swiss study on external costs of transport (INFRAS en Ecoplan, 2018), significantly higher costs for habitat loss and habitat fragmentation in mountain areas compared to non-mountain areas have been derived due to more diverse and more valuable ecosystems. The resulting mountain factors are 1.3 for road (motorways) and 1.4 for rail transport.
- **Accident costs:** For accident costs, there is also evidence for higher costs in mountain areas, mainly due to higher infrastructure investments to keep the accident rate as low as possible. For the first time, a mountain factor has been derived for accident costs in the EUSALP (2017) study. The calculation is based on an avoidance cost approach taking into account additional infrastructure safety measures on roads in Alpine corridors. The resulting factor for accident cost in mountain areas is around 5.
- **Climate change costs:** For climate change, a mountain factor has been checked in the EUSALP (2017) study. The conclusion was that no mountain factor cannot be derived for methodological reasons (it is a global issue with global effects).

10.4 Further externalities of transport

There are several other negative externalities of transport that can be mentioned, but that are only partially covered in literature:
- **Separation costs in urban areas:** large transport infrastructures in urban areas (mainly motorways and large rail fields) lead to separation effects and time losses for pedestrians.
- **Land use and ecosystem damage for upstream processes:** Different upstream processes of transport can lead to ecosystem damage and/or land use, e.g. the electricity generation or the exploitation of mineral oil products. The external costs of those effects are not in the main focus of the Handbook, although they are relevant. Additionally, there are existing some selected studies on external costs associated with those processes (e.g. Mattmann et al. 2016), but no well accepted cost factors, e.g. for different land use or ecosystem damage due to different types of electricity generation.
- **Cost of nuclear risks:** Another type of upstream cost from energy production is the risks from nuclear power plants. The risk of a nuclear incident has a very low probability but a potentially very high damage potential (a 'Damocles risk'). Therefore, it is very difficult to quantify the corresponding external costs. In addition to the costs of potential nuclear incidents, the disposal of nuclear waste is linked to costs (the costs of the disposal, often not covered in the electricity production costs; and also the risk of the disposal). The nuclear risks are a relevant externality, although it can hardly be quantified. Some older studies cover the costs due to nuclear power risks, however, the basis for monetizing those external effects is very old and no broadly accepted new studies on the cost of nuclear power risks have been conducted. Hence, this Handbook does not include cost factors for the nuclear power risks (in line with previous versions of the Handbook).

11 Synthesis

11.1 Introduction

This chapter contains the overall results on average and total external costs. First the total external costs are discussed, then the average external costs. All figures refer to the EU28 member states for the year 2016. The congestion costs are not shown in certain graphs because they cannot be shown for all vehicle types. However, the sum of the congestion costs is included in the analysis.

11.2 Overview total and average external costs

11.2.1 Total external costs

Figure 12 presents the total external costs of transport for EU28 by transport mode and cost category for 2016. The total external costs for road, rail, inland waterway transport, aviation and maritime (excluding congestion costs, because they are not calculated for all modes) amount to € 716 billion, which corresponds to 4.8% of the total GDP in EU28. The congestion costs amount to another € 271 billion for 2016 (delay costs generated by road transport modes)[42]. The total external costs including congestion costs sum up to € 987 billon (6.6% of the GDP).

For aviation and maritime transport, the detailed calculation of the external costs has only been done for for a set of selected airports and ports. The total external costs for EU28 for aviation and maritime have only been roughly estimated. Table 67 shows the results for the external costs for the selected airports and ports, Table 68 includes the indicative figures (estimations) for EU28 for aviation and maritime transport[43]. For the selected 33 EU airports the external costs amount to € 33 billion, for the selected 34 EU ports the costs amount to € 44 billion.

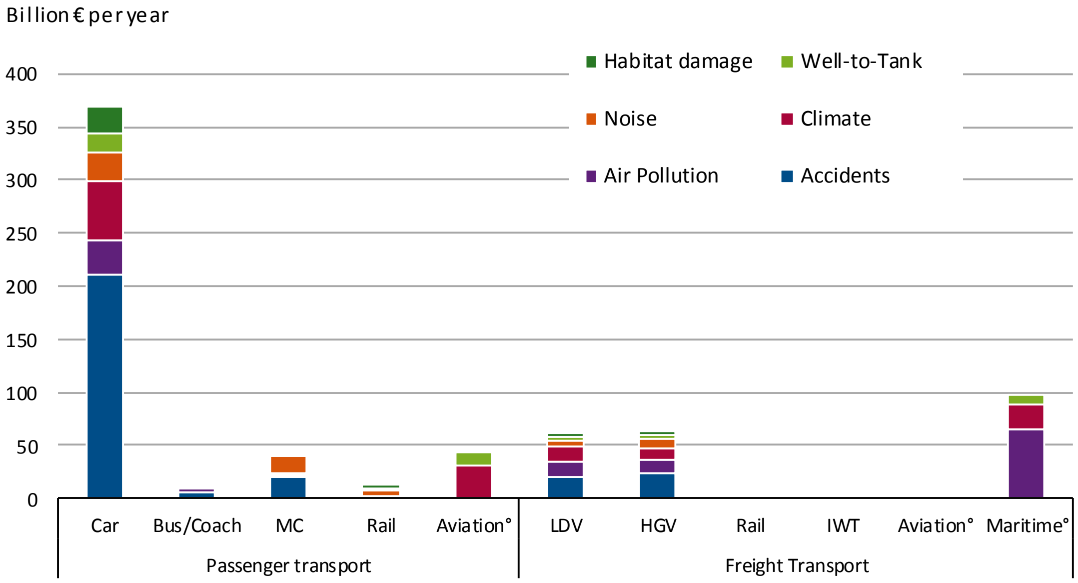
The most important cost category is accident costs equating to 29% of the total costs, followed by the congestion costs (27%) (see Figure 13). Climate change and air pollution costs both contribute to 14% of the total costs, noise costs to 7% and habitat damage to 4% of the total costs. Well to tank emission costs due to energy production and distribution lead to 5% of the costs.

Road transport is the predominant mode that causes by far the most external costs (83% of the total costs incl. aviation and maritime; 97.5% excl. aviation and maritime). Maritime transport causes 10%, aviation 5%, rail transport 1.8% and inland waterways 0.3% of the costs (see Figure 14). 69% of the total costs are due to passenger transport, 31% of the costs are caused by freight transport (including LCVs).

[42] Please notice, that part of these delay costs are internalised and hence that they are only partly external. The size of the external part of the delay costs is unknown.

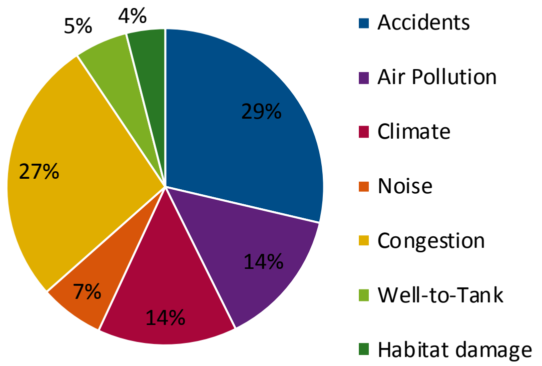
[43] Not for all external costs categories an estimation of the total EU28 costs for aviation and maritime can be calculated. For those (small) cost categories without EU28 estimation, the results for the selected airports and ports have been used.

Figure 12 - Total external costs 2016 for EU28 (excluding congestion)



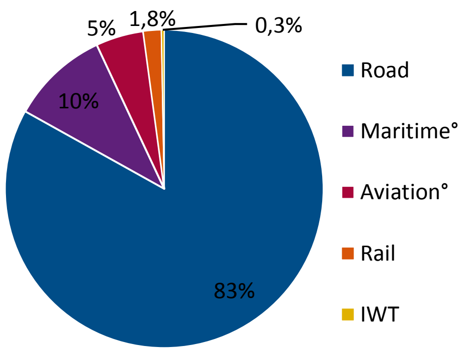
° Data for aviation and maritime: rough estimations for EU28.

Figure 13 - Share of the different cost categories on total external costs 2016 for EU28



Including data for aviation and maritime: rough estimations for EU28.

Figure 14 - Share of the different transport modes on total external costs 2016 for EU28



* Data for aviation and maritime: rough estimations for EU28.

The total external costs per country are shown for road, rail and IWT in Table 64[44]. This table also shows the share of these costs in the national GDP. This share range from 3.4% in Norway to over 7% in Portugal and Luxembourg.

Table 64 – Total external costs 2016 for road transport, rail transport and IWT per country

Country	Road (bn €)	Rail (bn €)	IWT (bn €)	Total (bn €)	% of GDP
EU 28	820.4	17.87	2.90	841.1	5.7%
Austria	18.3	0.85	0.044	19.2	5.9%
Belgium	26.4	0.42	0.183	27.0	7.0%
Bulgaria	6.5	0.12	0.047	6.6	6.5%
Croatia	5.0	0.07	0.015	5.1	6.9%
Cyprus	1.1	-	-	1.1	5.1%
Czech Republic	13.6	0.40	0.004	14.0	5.2%
Denmark	8.2	0.18	-	8.4	4.1%
Estonia	1.5	0.04	0.014	1.5	5.3%
Finland	7.4	0.23	0.073	7.7	4.4%
France	109.1	1.76	0.181	111.0	5.5%
Germany	165.7	5.37	1.228	172.3	5.8%
Greece	12.8	0.06	-	12.8	6.0%
Hungary	11.1	0.43	0.037	11.5	6.0%
Ireland	14.3	0.06	-	14.4	5.7%
Italy	115.0	2.20	0.009	117.2	6.8%
Latvia	2.3	0.18	-	2.5	6.7%
Lithuania	3.9	0.12	-	4.0	6.3%
Luxembourg	3.2	0.03	0.009	3.3	7.5%
Malta	0.4	-	-	0.4	3.6%
Netherlands	29.6	0.35	0.848	30.8	4.9%
Poland	40.2	1.28	0.018	41.5	5.5%
Portugal	16.8	0.18	-	16.9	7.2%
Romania	21.2	0.46	0.171	21.8	6.5%
Slovakia	5.4	0.33	0.012	5.7	4.7%
Slovenia	2.7	0.05	-	2.7	5.5%
Spain	64.3	0.83	-	65.1	5.2%
Sweden	15.3	0.46	-	15.8	4.5%
United Kingdom	99.4	1.42	0.009	100.8	4.9%
Norway	7.4	0.17	-	7.6	3.4%
Switzerland	15.3	0.76	0.001	16.1	4.1%

[44] As not all ports and airports are included, they have to be excluded when comparing different countries. Otherwise small countries where e.g. all air traffic takes places in one airport would see a higher cost as share of GDP only because all its aviation activity is accounted for.

Table 65 – Total external costs 2016 for EU28 passenger transport by cost category and transport mode

	Passenger Transport								
	Road						Rail		
	Pass car - petrol	Pass car - diesel	Pass car - total	Bus	Coach	MC	High-speed Train	Electric pax convent (non high speed)	Diesel tot pax
Cost category	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**
Accidents	210.2			5.3		21.0	0.06	2.0	
Air Pollution	8.6	24.8	33.4	1.4	2.7	1.8	0.002	0.03	0.52
Climate	32.0	23.5	55.6	0.8	1.6	1.5	0.00	0.00	0.22
Noise	13.8	12.4	26.2	0.8	0.9	14.8	0.4	2.6	0.9
Congestion *	196.1			4.5					
Well-to-Tank	10.4	7.7	18.1	0.3	0.5	0.8	0.3	2.7	0.1
Habitat damage	14.1	11.8	25.9	0.2	0.4	0.5	0.7	1.4	0.5
Total			**565.4**	**19.3**		**40.5**	**1.4**	**11.0**	
Total per mode	**625.2**						**12.5**		
Total as % of EU28 GDP	**4.2%**						**0.1%**		
Total passenger transport	**637.7**								

* Congestion in terms of delay cost generated by the various vehicle categories.

Table 66 – Total external costs 2016 for EU28 freight transport by cost category and transport mode

	Freight Transport						
	Road				Rail		IWT
	LCV-petrol	LCV-diesel	LCV-total	HGV - total	Electric freight	Diesel freight	Inland vessel
Cost category	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**
Accidents	19.8			23.0	0.3		0.1
Air Pollution	0.3	15.2	15.5	13.9	0.01	0.7	1.9
Climate	0.7	12.5	13.2	9.6	0.00	0.2	0.4
Noise	5.4			9.1	2.1	0.4	
Congestion*	55.5			14.6			
Well-to-Tank	0.2	3.6	3.8	3.7	0.5	0.1	0.2
Habitat damage	0.2	4.2	4.4	3.6	0.8	0.2	0.3
Total			**117.6**	**77.5**	**5.4**		**2.9**
Total per mode	**195.1**				**5.4**		**2.9**
Total as % of EU28 GDP	**1.31%**				**0.04%**		**0.02%**
Total freight transport	**203.4**						

* Congestion in terms of delay cost generated by the various vehicle categories.

For aviation and maritime transport the total costs have been calculated only for selected airports and ports. The total and average costs for aviation and maritime shipping for the selected (air)ports are shown in the following table.

Table 67 – Total external costs for selected EU28 (air)ports

	Aviation							Maritime
	Passenger			Freight			Total	
	Short-passenger	Medium-passenger	Long-passenger	Short-belly freight	Medium-belly freight	Long-belly freight	Aviation	Maritime ship
Cost category	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**	**bn €/a**
Accidents			0.1				0.1	0.1
Air Pollution	0.24	0.32	0.30	0.03	0.06	0.06	1.0	29.1
Climate	1.9	4.9	12.3	0.21	0.63	2.06	22.0	10.6
Noise			0.8				0.8	n/a
Congestion**			n/a				n/a	n/a
Well-to-Tank	0.86	1.84	4.93	0.09	0.26	0.90	8.9	3.9
Habitat damage			0.050			0.006	0.056	n/a
Total selected (air)ports			**28.6***			**4.3**	**32.9**	**43.6**
Total for selected (air)ports as % of EU28 GDP			**0.2%**			**0.03%**		**0.3%**

* Noise and accident costs have been allocated to passenger transport.

In addition, the total for the selected (air)ports have been extrapolated to retrieve estimates for EU28, for the most important cost categories. It should be noted that these estimates are relatively rough, as they assume that the the transport to/from the selected (air)ports (in terms of aircraft, ships and distances) are representative for the entire EU.

Table 68 – Indicative estimates for the most relevant total external costs for all EU28 (air)ports

	Aviation[45]	Maritime
Cost category	**bn €/a**	**bn €/a**
Air Pollution	n/a	65
Climate	33	24*
Well-to-Tank	13	9
Other cost categories**	2	0.1
Total EU28	**48**	**98**
Total for EU28 as % of EU28 GDP	**0.3%**	**0.7%**

* These total climate costs for maritime shipping have been based on the transport performance, in order to be consistent with the other transport modes and cost categories. The 2018 DG MOVE pocketbook reports 167.2 million tonnes CO_2 equivalent by navigation, out of which 20.3 is domestic navigation (which includes inland waterways). According to these data the climate cost of maritime and inland waterways together are 16.7 bn €. As the climate costs of inland navigation are 0.4 bn € (see Table 66), the costs of maritime shipping amount 16.3 bn €, according to these data. However, these data are based on bunkered fuels which is not a appropriate proxy for the fuel consumed for the international maritime shipping to/from EU ports.

** For the (small) cost categories for which no estimations of EU28 was available, the results for the selected airports and ports have been used.

11.2.2 Average external costs

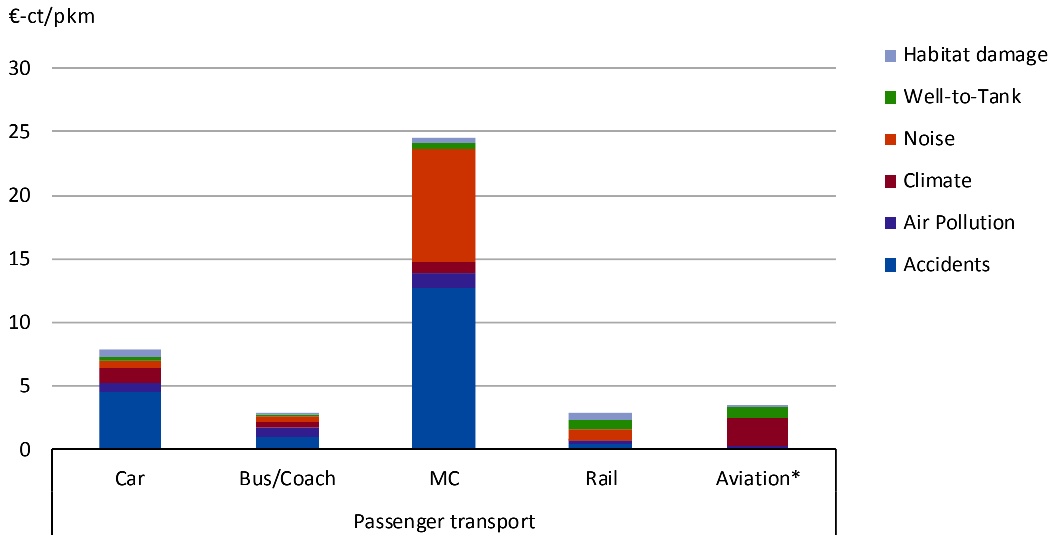
The average external costs of transport are expressed in Euro cent per pkm and tkm. Looking at passenger transport (see Figure 15), passenger cars cause external costs of €-cent 7.8 per pkm without congestion and 12.0 €-cent per pkm including congestion. The average costs of passenger rail transport amount to €-cent 2.8 per pkm, which is 2.8 times lower than the costs for the road sector (without congestion). Average costs for rail transport differ a lot between electric trains and diesel trains. Due to significantly higher climate change and air pollution costs, the average costs of diesel trains are €-cent 3.9 per pkm, whereas the costs of electric trains only amount to €-cent 2.6 per pkm (average of all electric trains). The cost of high speed rail is even lower, i.e. €-cent 1.3 per pkm. A second reason for this difference (apart from the higher emission factors) is the fact that passenger diesel trains have lower load factors (number of passengers per vehicle) than electric trains. Motorcycles cause by far the highest average external costs per pkm, which is a result of their high accident and noise costs (plus their low occupancy rate).

The average costs of air transport are around €-cent 3.4 per pkm, which is only about 20% higher than average rail costs. However, the result for air transport is an average, including data for short, medium and also long haul flights to and from European airports.
The average costs between these distance classes differ from €-cent 4.3 per pkm for short haul flights, to €-cent 2.8 per pkm for medium haul and €-cent 3.2 per pkm for long haul. When comparing aviation and rail for the same distance classes, external costs of aviation (short haul flights: 4.3 €-cent/pkm) are 3 times higher than rail (high speed rail: 1.3 €-cent/pkm).

[45] The total climate change costs of aviation for the total EU28 have been estimated roughly the following: the total CO_2 emission of aviation in EU28 have been 163.7 Mio. t CO_2 eq. in 2016. Under the assumption that for aviative greenhouse gas emissions an emission weighting factor (EWF) of 2.0 is applicaple to the total CO_2 emissions and the climate cost factor of 100 €/t CO_2 eq., the total climate costs are around 32.7 bn €/a.
The WTT costs have been based on the Climate costs

Main cost drivers for the external costs of aviation are the share of the LTO cycle of the total flight (which is higher for short haul flights), the size and fuel use of the aircrafts and the load factor. For road transport, the predominant cost categories are accidents and emissions (climate change, air pollution). For air transport, climate change costs are the main category. Please note that for aviation and maritime, the EU average costs are averages for the selected EU-(air)ports that may not be representative for all EU (air)ports.

Figure 15 - Average external costs 2016 for EU28: passenger transport (excluding congestion)

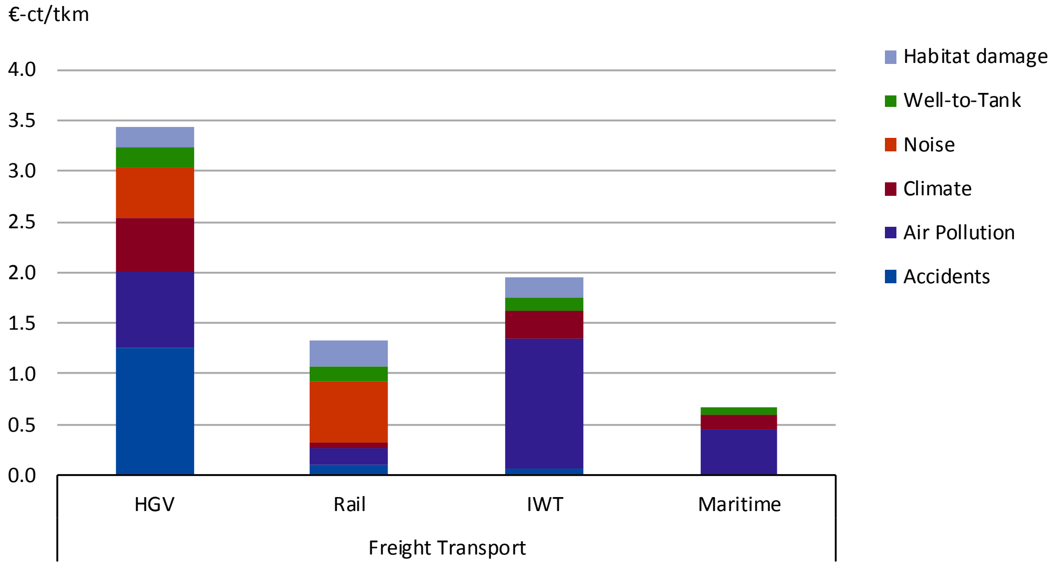


* Aviation: average for selected EU28 airports.

For freight transport (see Figure 16), the average costs for rail transport are 1.3 €-cent per tkm. The costs for inland waterways are slightly higher (€-cent 1.9 per tkm) than for rail. The average costs for road freight transport (HGVs) are €-cent 3.4 per tkm (without congestion) which is 2.6 times higher than for rail. Including congestion, the average costs for road freight transport are 4.2 €-cent per tkm (3.2 times higher than for rail freight transport). It may be surprising that the noise costs for rail are higher per tkm than for a HGV. This is due to the data used from the noise maps. There are separate maps for road and rail transport, which reveal that fewer people experience noise nuisance per vkm on the road, compared to the number of people that experience noise nuisance per vkm on the railway tracks. For air cargo freight transport, no external costs have been calculated due to lack of data.

Light commercial vehicles (LCV) are used both for freight and passenger transport. Therefore, a comparison with other passenger or freight modes cannot be easily made. The derivation of average costs per tkm or pkm is not feasible as it is not known which part of the transport performance (vkm) is freight or passenger transport. Therefore, the results for LCV are presented in €-cent per vkm (see Table 69).

Figure 16 - Average external costs 2016 for EU28: freight transport (excluding congestion)



* Maritime: average for selected EU28 ports.

Table 69 – Average external costs 2016 for EU-28

	Passenger transport						Freight Transport		
	Car	Bus/Coach°	MC	Rail	Aviation°*	LCV	HGV	Rail	IWT
Cost category	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/vkm	€-cent/tkm	€-cent/tkm	€-cent/tkm
Accidents	4.5	1.0	12.7	0.5	0.02	4.1	1.3	0.1	0.1
Air Pollution	0.7	0.7	1.1	0.12	0.2	3.4	0.8	0.2	1.3
Climate	1.2	0.5	0.9	0.05	2.2	2.8	0.5	0.06	0.3
Noise	0.6	0.3	9.0	0.9	0.2	1.1	0.5	0.6	n.a.
Congestion**	4.2	0.8	0.0	0.0	0.0	11.6	0.8	0.0	0.0
Well-to-Tank	0.4	0.2	0.5	0.7	0.9	0.8	0.2	0.2	0.1
Habitat damage	0.5	0.1	0.3	0.6	0.01	0.9	0.2	0.2	0.2
Total	**12.0**	**3.6**	**24.5**	**2.8**	**3.4**	**24.7**	**4.2**	**1.3**	**1.9**

° Bus/coach: average for bus and coach. Aviation: average for the different distance classes.

* For aviation, the EU average costs are averages for the selected EU airports that may not be representative for all EU airports.

** Congestion in terms of delay cost.

Table 70 – Average external costs 2016 for EU28 passenger transport by cost category and transport mode

	Passenger Transport								
	Road						Rail		
	Pass car - petrol	Pass car - diesel	Pass car - total	Bus	Coach	MC	High speed Train	Electric pax tot	Diesel pax
Cost category	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/pkm	€-cent/pkm
Accidents	4.5	4.5	4.5	1.0	1.0	12.7	0.1	0.5	0.5
Air Pollution	0.3	1.2	0.7	0.8	0.7	1.1	0.0	0.01	0.80
Climate	1.2	1.1	1.2	0.5	0.4	0.9	0.0	0.0	0.3
Noise	0.5	0.6	0.6	0.4	0.2	9.0	0.3	0.8	1.4
Congestion**	4.2	4.2	4.2	0.8	0.8				
Well-to-Tank	0.4	0.4	0.4	0.2	0.1	0.5	0.3	0.8	0.1
Habitat damage	0.5	0.6	0.5	0.1	0.1	0.3	0.6	0.6	0.8
Total	**11.6**	**12.4**	**12.0**	**3.7**	**3.5**	**24.5**	**1.3**	**2.6**	**3.9**

** Congestion in terms of delay cost.

Table 71 - Average external costs 2016 for EU28 freight transport by cost category and transport mode

	Freight Transport					
	Road			Rail		IWT
	LCV-petrol	LCV-diesel	HGV - total	Electric freight	Diesel freight	Inland vessel
Cost category	**€-cent/vkm**	**€-cent/vkm**	**€-cent/tkm**	**€-cent/tkm**	**€-cent/tkm**	**€-cent/tkm**
Accidents	4.1	4.1	1.3	0.1	0.1	0.1
Air Pollution	1.2	3.4	0.8	0.0	0.7	1.3
Climate	2.6	2.8	0.5	0.0	0.2	0.3
Noise	1.1	1.1	0.5	0.6	0.4	n/a
Congestion**	11.6	11.6	0.8			
Well-to-Tank	0.8	0.8	0.2	0.2	0.1	0.1
Habitat damage	0.9	0.9	0.2	0.2	0.2	0.2
Total	**22.3**	**24.7**	**4.2**	**1.1**	**1.8**	**1.9**

** Congestion in terms of delay cost.

Table 72 - Average external costs for selected EU28 (air)ports

	Aviation passenger			Maritime
	Short haul	Medium haul	Long haul	Maritime ship
Cost category	**€-cent/pkm**	**€-cent/pkm**	**€-cent/pkm**	**€-cent/tkm**
Accidents	0.04	0.01	0.00	0.001
Air Pollution	0.30	0.13	0.06	0.44
Climate	2.39	1.85	2.24	0.16
Noise	0.46	0.11	0.01	n/a
Congestion	n/a	n/a	n/a	n/a
Well-to-Tank	1.06	0.70	0.91	0.06
Habitat damage	0.03	0.01	0.00	n/a
Total	**4.26**	**2.81**	**3.22**	**0.66**

11.2.3 Average external costs per country

The results per country are presented in Table 73. It has to be noted that the accuracy level of the disaggregated results per country is in general considerably lower than at the aggregate EU level.

The results per country can differ for many different reasons. Some of the most important reasons for different average costs are differences in:
- GDP per capita (PPP adjusted);
- load factors (for all transport modes);
- vehicle stock (share of efficient, low-emission vehicles);
- share of diesel and electric trains;
- electricity mix for rail;
- population density (mainly for noise and air pollution cost);
- accident risk.

Table 73 – Average external costs 2016 for EU28 by country and transport mode (excluding congestion)*

	Passenger transport							Freight Transport		
	Car	Bus	MC	Rail high speed**	Rail electric	Rail diesel	LDV	HGV	Rail	IWT°
Country	**€-cent/ pkm**	**€-cent/ pkm**	**€-cent/ pkm**	**€-cent/ pkm**	**€-cent/ pkm**	**€-cent/ pkm**	**€-cent/ vkm**	**€-cent/ tkm**	**€-cent/ tkm**	**€-cent/ tkm**
EU28 Aggregate	**7.8**	**2.9**	**24.5**	**1.3**	**2.6**	**3.9**	**13.1**	**3.4**	**1.3**	**1.9**
Austria	12.8	3.8	69.3		2.9	8.4	16.3	4.3	3.2	2.5
Belgium	10.9	4.2	33.4	2.6	2.8	13.9	22.5	5.7	1.6	1.8
Bulgaria	5.9	2.2	43.3		5.4	5.3	8.6	2.6	1.1	0.8
Croatia	10.2	2.8	17.9		3.8	5.4	11.0	3.0	1.0	1.7
Cyprus	6.0	2.0	21.1		0.0	0.0	10.5	3.8	0.0	0.0
Czech Republic	8.0	3.1	16.8		2.9	5.1	14.2	4.4	1.2	11.7
Denmark	5.8	2.2	21.7		2.6	2.1	9.7	4.4	0.9	0.0
Estonia	6.7	3.2	13.4		3.6	2.7	8.9	2.0	1.0	1.0
Finland	5.2	1.7	11.8		2.9	3.3	10.6	2.7	1.3	56.4
France	6.5	2.8	20.7	0.9	1.4	2.5	11.2	3.7	1.5	2.1
Germany	9.8	3.6	40.4	1.6	3.5	7.1	19.3	4.4	1.9	2.2
Greece	4.6	1.5	16.3		8.8	3.8	10.7	2.4	1.9	0.0
Hungary	9.1	2.6	21.4		4.3	5.9	18.2	3.5	0.9	2.0
Ireland	5.9	2.4	14.9		5.8	2.5	10.1	2.7	4.1	0.0
Italy	7.9	2.6	21.8	1.9	3.0	13.4	13.0	4.5	3.0	15.2
Latvia	7.8	2.9	82.9		2.0	2.2	12.3	2.7	0.6	0.0
Lithuania	7.1	2.5	14.0		5.9	5.4	11.1	2.4	0.6	0.0
Luxembourg	11.8	4.6	30.6		5.6	26.9	15.9	3.2	3.7	3.7
Malta	8.8	2.6	36.4		0.0	0.0	19.4	2.3	0.0	0.0
Netherlands	8.6	4.3	23.1	1.7	1.6	2.2	16.2	3.3	1.1	1.7
Poland	7.8	2.7	23.1		5.0	4.1	8.6	2.5	1.0	20.1
Portugal	6.6	2.4	28.2		2.9	3.8	11.8	2.6	1.9	0.0
Romania	10.6	4.2	77.3		6.3	6.2	35.8	3.3	1.1	1.3
Slovakia	8.5	3.4	38.7		5.6	8.1	9.8	3.2	1.7	1.6
Slovenia	5.4	1.8	28.0		2.4	5.6	7.2	2.5	0.7	0.0

	Passenger transport							Freight Transport		
	Car	Bus	MC	Rail high speed**	Rail electric	Rail diesel	LDV	HGV	Rail	IWT°
Country	€-cent/ pkm	€-cent/ pkm	€-cent/ pkm	€-cent/ pkm	€-cent/ pkm	€-cent/ pkm	€-cent/ vkm	€-cent/ tkm	€-cent/ tkm	€-cent/ tkm
Spain	8.0	2.7	22.9	1.7	2.8	2.1	19.2	2.6	1.4	0.0
Sweden	5.4	1.8	27.7		1.9	6.5	9.5	2.7	1.6	0.0
United Kingdom	6.2	4.0	30.0	1.0	1.5	2.3	9.9	3.0	0.8	5.5
Norway	4.4	2.7	21.4		2.8	2.8	10.6	2.8	2.4	0.0
Switzerland	9.5	3.7	56.1		2.5	3.4	21.8	6.7	4.0	1.9

* Results are presented for all countries and modes where transport acitivty is reported. Empty cells mean no activity data.

** For rail high speed, activity is considered only in countries where high speed rail infrastructure exists (and not for countries with only high speed service), in order to be consistent with the other reports (infrastructure costs).

° For some countries, the reported transport performance of IWT is low, altough the inland waterway network is still substantially large, leading to high average habitat damage costs (mainly Finland, but also Poland, Italy, Czech Republic).

11.3 Comparison with previous studies

11.3.1 Previous Handbooks

Although the method used to calculate the average costs of the EU28 member states in this study is largely the same as in the previous 2014 Handbook, a direct comparison is not easy. For instance, the costs in the first edition of the Handbook were presented for the price level in 2000. The second edition of the Handbook (2014 edition) presented costs at the 2010 price level. This Handbook is presented using 2016 prices. On average EU prices increased by 35% and 8% since the first and second edition of the Handbook respectively. Furthermore, the current emission factors come from various sources, e.g. COPERT v5 for road transport and HBEFA 3.3 was used where COPERT had gaps. In the previous Handbook, the emission factors came from TREMOVE, which is based on an older version of COPERT. The damage cost rates for the pollutants taken into account (NO_x, SO_2, NMVOC and PM) and the climate cost rate are also different from the last Handbook. In addition, transport performances have changed, which also has an impact on average costs. Therefore, a comparison between the previous Handbook and the current one is not easy.
When comparing the results, the reasons for the changes can be very different.

Accidents

In the first edition of the Handbook no average road accident costs were presented, only marginal costs were provided. Costs were only presented at the country level and not presented for an EU average in the first Handbook. The marginal costs were shown to range from negative to positive, depending on the degree to which the average accident risk is internalised by the transport users. The 2014 Handbook also only presented marginal costs, and did not have average costs available. The marginal costs from the 2014 Handbook were available for an EU average, and were all positive in the range of 0.1-0.3 €-cent per vkm for passenger cars, 0.2-1.9 €-cent per vkm for motorcycles and 0.8-1.2 €-cent per vkm for HGVs. This edition of the Handbook provides EU28 marginal costs ranging from 0.25-1.41 €-cent per pkm for passenger cars, -3.21-4.42 €-cent per pkm for motorcycles, 0.05-0.80 €-cent per pkm for buses and coaches, 0.37-0.84 €-cent per vkm for LCVs and 0.07-0.13 €-cent per tkm for HGVs. These figures reveal marginal costs are only negative for vulnerable road users such as motorcycles.

This edition of the Handbook goes further and also presents average costs of 7.2, 13.3 and 15.5 €-cent per vkm for passenger cars, motorcycles and HGV respectively. In addition, this Handbook also provides average costs for LCVs (4.1 €-cent per vkm) and buses and coaches (18.9 €-cent per vkm).

Average accident costs for rail transport were estimated to be € 0.08-0.30 per vkm in the first Handbook. In the second Handbook costs were € 0.20 per 1,000 tkm for freight trains and € 0.60 per 1,000 pkm for passenger trains, taken from (CE Delft, INFRAS & Fraunhofer ISI, 2011). For a comparison with those values please see Section 11.3.2. This Handbook presents costs of € 0.18 per vkm for high speed trains (0.06 €-cent per pkm), and € 0.52 per vkm for all passenger trains (0.47 €-cent per pkm), roughly in line with the costs from the first Handbook.

The accident costs for aviation (expressed per LTO) ranged from € 12-209 in the first Handbook. In the second Handbook costs were € 0.50 per 1,000 pkm for passenger aviation, taken from (CE Delft, INFRAS & Fraunhofer ISI, 2011). For a comparison with those values please see Section 11.3.2. Costs per LTO range from € 12-46 in this Handbook, providing a narrower range than the values from the first Handbook. Expressed per pkm the costs ranged from 0.001 to 0.04 €-cent per pkm, depending on whether a flight is short-, medium- or long haul.

Fundamental differences in the cost estimates between earlier editions of the Handbook and the current edition can largely be explained because of the higher valuation of the fatalities, serious injuries and slight injuries (higher VSL), an overall increase in price level (8-35% depending on which edition of the Handbook the figures are compared to), which are to a certain extent compensated by a reduction in the accident rate. Particularly for road accidents the latter has been noticeable, it has more than halved since the base year from the first edition of the Handbook (2000) and declined by 19% since the base year from the second edition of the Handbook (2010).

Air pollution

Over 370 different emission and finally cost factors are reported for passenger cars in the actual Handbook, which is a lot more than in the last Handbook. It is therefore difficult to compare all of them individually. The main reasons for the differences between the versions of the Handbook is the different/new sources for emission factors. For road, with COPERT, a completely new data source has been taken. Also for the other cost categories, more recent and very often more differentiated sources for emission factors have been applied. Another important reason is the fact that the present Handbook now includes all relevant damage effects (health, crop loss, biodiversity loss, material/building damage), whereas previous Hanbooks only focused on health effects.

The differences in the cost factors used for air pollution costs is not so large, as the new factors are based on NEEDS (updated values). An important factor for the update of the cost factors per air pollutant is the new Value Of Life Year lost (VOLY), which is substantially (roughly 50%) higher than in the last Handbook. Therefore, the cost factors are substantially higher, which often overcompensates the slightly lower emission factors in the present Handbook.

When looking at the different vehicle types, it can be said that diesel vehicles have slightly higher air pollution cost rates than in the last study. The cost rates for petrol vehicles are significantly higher than in the last study. In the case of LCV, the cost rates are higher for both petrol and diesel vehicles. The cost rates for buses and coaches in the new study are slightly lower than in the old study. The new cost rates per tkm for HGVs are also generally lower than in the last study.

The marginal external air pollution costs for rail are significantly lower than in the last Handbook mainly because of the different emissions data used.

For aviation, the new Handbook shows higher average external air pollution costs than the previous study. For inland waterways, the average air pollution costs, are difficult to compare, due to a very different set of vessel types. In general, they are slightly lower than in the previous study.

Climate change

For most road vehicle types the average costs of climate change are slightly higher in the present Handbook than in the previous version. The main reason for this is the higher CO_2 cost factor (100 € per tonne of CO_2 eq. in the present study, compared to € 90 per tonne of CO_2 eq. in the previous Handbook).

For aviation, the new Handbook shows significantly higher average external climate costs than the previous study. The different aircraft types are more differentiated in the new version of the manual, but nevertheless it is clear that the average costs are higher.

Noise

No average road noise costs were presented at the country level in the first edition of the Handbook. The second edition of the Handbook only presents illustrative average noise costs for German motorways. These were 0.15, 0.61, 0.18, 0.48 and 0.44-0.61 €-cent per vkm for cars, motorcycles, LCVs, buses and HGVs respectively. This Handbook's values for German roads are 0.5, 3.6, 0.7, 3.6 and 2.6-4.5 €-cent per vkm respectively. These values are roughly a factor of 3-5 higher, a difference which can largely be explained because of a better correction for missing data, and new insights from the literature (e.g. a higher valuation of noise annoyance and the inclusion of new health endpoints). This higher valuation of noise annoyance is in part due to the fact that annoyance is no longer valued as being linear, rather, higher valuation is given at higher noise levels. New health endpoints that are incorporated in this Handbook are strokes and dementia.

No average rail noise costs were presented in either the first or second edition of the Handbook. This is a novel aspect in this Handbook.

No average noise costs were presented for aviation in the first edition of the Handbook, although both this edition and the second edition presented average noise costs per LTO at the airport level. A comparison can be drawn between the airports that overlap.
For instance, at London Heathrow the average noise costs per LTO were € 652 per LTO in the second edition of the Handbook. In this edition, the costs are € 1,549 per LTO.
Similar increases in costs can be witnessed for a number of the other major airports in Europe, e.g. Amsterdam (from € 39 to € 118), Paris Charles de Gaulle (from € 111 to € 256) and Frankfurt (from € 180 to € 376). In general, the trend holds for all airports in Europe,

and can be explained byby better corrections for missing data, and a higher valuation of noise annoyance and health.

Congestion

In the previous Handbook road congestion costs were firstly estimated for UK using the FORGE model. This model was used to quantify road congestion by estimating speed-flow relations of UK road networks, specific to areas and road types. The FORGE model distinguished between motorways and other roads and the results for ‘conurbations’ (other large cities, except for London) were used as a proxy for typical metropolitan areas. Given the level of congestion in different areas and road types, marginals cost of congestion were estimated for the UK. Values for EU Member States were then derived by means of value transfer.

In this edition of the Handbook, the methodology for congestion makes reference to different conditions (i.e., road types and level of congestion) and the level of congestion is not based on modelled results for one country only, but on observed measures for several cities and the whole European main road network. Furthermore, a different source has been used as reference for the Value of Time.

Importantly, the methodology adopted in the previous Handbook did not lead to the estimation of total and average congestion costs. The social marginal congestion costs estimated in this Handbook are also different from those of the previous version. The values estimated in this version are for segment AC in Figure 7, according to the definition in (Li, et al., 2016), those estimated in the previous one (i.e., the Efficient Marginal Congestion Cost, EMCC) are for segment BD. Moreover, the methodolgy developed within this Handbook calculates the incurred social marginal congestion cost and then estimates the generated social margial congestion cost through a simplified approach to allow for comparability with the other external costs. Figures and trends on congestion costs are compared with respect to the 2011 version of the Handbook, as reported in Section 11.3.2.

In comparison with the Study on urban mobility prepared for DG Move Branningan et al. (2016) this Handbook applies in principle the same methodological approach. Nevertheless, different data sources are used for some input values and/or the same information in a more recent release. In particular, the Value of Time plays a key role for the magnitude of the estimation of total costs in terms of delay and deadweight loss; i.e. the value of Time used as reference in this Handbook is larger than the previous datasource, therefore it contributes to estimate an increased value of total congestion costs (i.e. about 50% for passenger cars) in terms of delay cost and deadweight loss with respect to the study mentioned above.

Well-to-tank emissions

The data base for well-to-tank emissions are completely new. One main reason for differences to the previous Handbook is the slightly higher CO_2 cost factor. Also, the cost factors for air pollution are higher (mainly due to a higher VOLY).

Looking at the different vehicle types, the cost factors for passenger cars and LCV are very similar to the previous Handbook. For trucks, the costs are higher in the present Handbook. So, for road transport the higher cost factors are compensated by the lower emission factors.

For rail, aviation and inland waterways the costs of well-to-tank emissions in the present Handbook are considerably higher than in the previous one. Here, both emission and (more important) cost factors are higher in the present Handbook.

11.3.2 Overview study 'External costs of transport in Europe' (2011)

The (CE Delft, INFRAS & Fraunhofer ISI, 2011) study was presented for the year 2008.

Accidents

The total costs of accidents presented in this Handbook are very much in line with those presented in the (CE Delft, INFRAS & Fraunhofer ISI, 2011) study. For motorcycles total accident costs fell from € 22 billion to € 21 billion. A similar decline was visible in the total accident costs for buses and coaches (from € 6.8 to € 5.3 billion). For the other road transport vehicle types, there was an increase in total accident costs. For HGVs the costs increased from € 20 to € 23 billion and for LCVs the costs increased from € 19 to € 20 billion. The biggest increase was visible for the total costs of accidents for passenger cars. Costs increased from € 157 billion to € 210 billion.

In general, the trends observed for total road accident costs were echoed by the average road accident costs. A decline was visible for motorcycles (from € 157 to € 127 per 1,000 pkm) and buses and coaches (from € 12.3 to € 9.8 per 1,000 pkm). The largest increase was visible for passenger cars, where average costs increased from € 32 to € 45 per 1,000 pkm. The average costs for HGVs also increased from € 10 to € 13 per 1,000 tkm.

There are three major factors that explain the differences in costs between this Handbook and the (CE Delft, INFRAS & Fraunhofer ISI, 2011) study. Firstly, a higher valuation was used for the cost of an injury or fatality. The largest parameter is the VSL, which is used as an input for the human costs. Because of the higher valuation of the VSL, the costs of a fatality, serious and slight injury were increased by 98%, 130% and 133% respectively, compared to the valuation in the (CE Delft, INFRAS & Fraunhofer ISI, 2011) study.
This effect should lead to higher costs in this Handbook in comparison with the (CE Delft, INFRAS & Fraunhofer ISI, 2011) study. Secondly, the studies look at a different price level. The inflation that took place between 2008 and 2016 results in 2016 prices being on average 12% higher than in 2008. This effect should also result in costs in this Handbook being higher than in the (CE Delft, INFRAS & Fraunhofer ISI, 2011) study. Thirdly, statistics show a decline in accidents in the period between 2008 and 2016 (for instance, the number of road fatalities has declined by 35% between 2008 and 2016).

For railway transport, the total costs of passenger rail and freight rail transport were € 0.2 billion and € 0.07 billion respectively in CE Delft, Infras & Fraunhofer ISI, (2011).
In this current Handbook, the total costs of passenger rail transport are € 2.1 billion and € 0.3 billion for freight rail transport. Similarly, average costs have also increased, from € 0.6 to € 4.7 per 1,000 pkm for passenger rail, and from € 0.2 to € 0.7 per 1,000 tkm for freight rail. This is a significant increase for both average and total costs which cannot solely be explained by the increased valuation and inflation (mentioned above). In this Handbook we use data from the European Railway Agency, from which we conclude that there are 737 fatalities and 556 serious injuries in the EU28. The CE Delft, Infras & Fraunhofer ISI (2011) used data from the UIC, where there were 114 fatalities and 612 serious injuries. These differences in input data explain the increased costs.

For aviation the total accident costs mentioned in CE Delft, Infras & Fraunhofer ISI (2011) amounted to € 223 million, and the average accident costs was € 0.5 per 1,000 pkm. In this Handbook the total costs of aviation amount to € 75 million. The difference in these numbers can be explained by the change in scope of this study. This Handbook only looks at 33 European airports, whereas CE Delft, Infras & Fraunhofer ISI (2011) look at all airports in the EU. For average costs the values in this Handbook are in line with CE Delft, Infras & Fraunhofer ISI (2011) at € 0.40, € 0.10 and € 0.01 per 1,000 pkm for short, medium and long-haul respectively.

For the two other transport modes (inland waterway transport and maritime transport) accident costs were not calculated in the CE Delft, Infras & Fraunhofer ISI (2011) study, which implies no comparison can be carried out.

Air pollution

The total air pollution costs for road, rail and air transport are very similar than in the last UIC study from 2011. For LCV, the costs are substantially higher, mainly due to better transport activity data and more recent emission factors. For inland waterways, the total air pollutant costs are almost double as high resulting from more recent transport acticity data and emission factors.

The average air pollution costs are on a similar level than in the UIC study from 2011. The main reasons for differences are the completely new set of emission factors, the new Value Of Life Year lost (VOLY), which is substantially (roughly 50%) higher than in the UIC study.

Climate change

The UIC study analysed the external climate costs using a low and a high scenario. The difference between the two scenarios was the climate cost factor which at that time ranged between € 42 and € 146. In the current study, a climate cost factor of € 100 is used. The two studies cannot be compared with each other on this point. In general however, it can be said that today’s average external climate costs lie between the high and low scenarios of the previous UIC study.

Noise

The total costs of noise presented in this Handbook are substantially higher than those presented in the CE Delft, Infras & Fraunhofer ISI (2011) study. Noise costs increased most for motorcycles and mopeds (a factor 7, from € 2.1 billion to € 14.8 billion) and for passenger cars (a factor 3, from € 8.2 billion to € 26.2 billion). Total costs more than doubled for LCVs (from € 2.1 billion to € 5.4 billion) and HGVs (from € 3.5 million to € 9.1 billion). The total noise costs for buses and coaches increased from € 0.9 billion to € 1.6 billion.

In general, the trends observed for total road noise costs were echoed by the average road noise costs. Average costs increased by a factor 6 (from € 14.4 to € 89.7 per 1,000 pkm) and 4 (from € 1.7 to € 5.5 per 1,000 pkm) for motorcycles and passenger cars respectively. Increases in average costs of a factor of 3 and 2 were observed for HGVs and buses/coaches respectively, mirroring the increases in total costs.

There are three major factors, apart from the different price levels (price year 2016 vs. price year 2008), that explain the differences in costs between this Handbook and the CE Delft, Infras & Fraunhofer ISI (2011) study. Firstly, a higher valuation was used for the cost of noise, in particular for the noise annoyance. New in this Handbook is the increased valuation with higher noise levels, this results in substantially higher costs per person annoyed in each noise bin. This explains part of the higher noise costs in this Handbook compared to CE Delft, Infras & Fraunhofer ISI (2011) study. Secondly, this study uses the noise maps from 2012, which are more recent than the ones used in CE Delft, Infras & Fraunhofer ISI (2011). It is likely that the increased urbanisation that took place over this period implies that more people are now exposed to (higher) noise levels, which results in higher noise costs in this Handbook compared to CE Delft, Infras & Fraunhofer ISI (2011). Thirdly, the noise maps are incomplete as there are agglomerations and countries with a reporting obligation that may not provide data. Furthermore, only some agglomerations have a reporting obligation, for agglomerations without a reporting obligation noise costs are not taken into account. Previous studies have attempted to correct the data for this effect, but this edition of the Handbook carries out a better and more detailed correction. This is a further reason for the noise costs being higher in this Handbook than in CE Delft, Infras & Fraunhofer ISI (2011).

For railway noise the total costs of passenger rail and freight rail transport were € 0.5 billion each in CE Delft, Infras & Fraunhofer ISI (2011). In this current Handbook, the total noise costs of passenger rail transport are € 3.9 billion and € 2.5 billion for freight rail transport. Similarly, average costs have also increased, from € 1.2 per 1,000 pkm to € 3.2, € 8.0 and € 13.8 per 1,000 pkm for high speed, electric and diesel passenger trains respectively. For freight rail costs increased form € 1.0 to € 6.5 and € 4.5 per 1,000 tkm for electric and diesel freight trains respectively. This increase is roughly in line with the increase in total costs. The costs have thus increased by a factor of 6 to 9 in between the studies, which can be explained by the fact that the previous study incorporated a rail bonus, whereas the current Handbook does not. As a result, higher rail costs prevail.

For aviation the total noise costs mentioned in CE Delft, Infras & Fraunhofer ISI (2011) amounted to € 0.5 billion, and the average noise costs were € 1.0 per 1,000 pkm. In this Handbook the total noise costs of aviation amount to € 0.84 billion. The increase in total costs is relatively small compared to the other modes. This can be explained by the change in scope of this study. This Handbook only looks at total noise from 33 European airports, whereas (CE Delft, Infras & Fraunhofer ISI (2011) look at all airports in the EU. For average costs the values in this Handbook are differentiated to distance, with short, medium and long haul noise costs being € 4.6, € 1.10 and € 0.14 per 1,000 pkm respectively.
This increase can be explained by the increase in the valuation of noise, and the improved corrections made to the noise maps.

For the two other transport modes (inland waterway transport and maritime transport) no noise costs were calculated in either study, as the noise exposure is considered negligible or non-existent as it usually takes place in sparsely populated areas. Furthermore, data on noise exposure from these modes is not available.

Congestion

The methodology and the measures of road congestion costs presented in this Handbook are similar to those applied in (CE Delft, Infras & Fraunhofer ISI (2011).

Furthermore, also the total costs of congestion presented in this Handbook are largely in line with the range of costs presented in the 2011 version of the Handbook (CE Delft, Infras and Fraunhofer ISI, 2011). For passenger cars both delay cost and deadweight loss are about 20%-25% higher than the maximum (i.e., € 196 billion versus € 161 billion for delay cost and € 33.5 billion versus € 26 billion for DWL, respectively). Total costs are about 45% lower than the minimum value for HGVs (€ 14.6 million in this version of the Handbook versus € 26.7 billion for delay cost and € 2.5 billion in this version of the Handbook versus € 4.3 billion for DWL), while for LCVs the total cost estimated in this Handbook are doubled with respect to the maximum reported in the 2011 version (€ 55.5 billion versus € 27.6 billion for delay cost and € 9.4 billion versus € 4.5 billion for DWL). The use of the different Value of Time can explain part of the different estimations.

11.4 Recommendations for further assessment

This Handbook provides a state of the art overview on the external costs of transport. However there are various topics that require further research. For each cost category, the main uncertainties have been discussed in the sections on the robustness of the results. All these can be interpreted as issues for further research. In addition there are some more general issues for further research. Overall the main issues for further research are:
- There appear to be significant inconsistencies between the available data sets on emissions factors (e.g. from COPERT), transport performance data (from Eurostat) and national emission reporting. This requires further harmonisation.
- Data on congestion and scarcity for non-road transport modes.
- Data on other external costs (e.g. nuclear risks).
- Level of internalisation by insurances for accident costs and immaterial damages for slight and serious injuries.
- Valuation of accidents for new categorisation of injuries (six categories of the MAIS scale instead of the ‘serious’ and ‘slight’ injuries).
- CO_2 avoidance cost for meeting the Paris agreement.
- The noise maps do not cover all infrastructure and locations.
- The data basis for the marginal accident and marginal noise costs.
- The air pollutant emission factors: to what extent do they fully reflect real world emissions, including potential degradation or removal of emission reduction equipment like particulate filters.

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A Economic valuation of human health

A.1 Introduction

Human health can be valued in a number of ways, which all slightly differ from each other. This can result in an overwhelming amount of terminology, and seeing the interlinkages between all of them can be quite confusing. In this chapter, we elaborate on the different ways in which human health can be valued, and how the terminologies can be converted. The valuation of human health is particularly relevant for the chapters on accidents (Chapter 3, Annex B), air pollution (Chapter 4, Annex C) and noise (Chapter 6, Annex E).

A.2 Indicators for human health

There is a large variety in indicators for human health. This section provides an overview of the main ways in which health can be quantified and valued. We distinguish two types of indicators: the first type reflects changes in health in terms of years (e.g. YOLL, YLD, DALY and QALY), the second type provides a valuation for an (un)healthy life(year) (e.g. VSL and VOLY).

A.2.1 Quantification of health in terms of years

Years of life lost

The Years of Life Lost (YOLL) is the amount of years of premature mortality as a result of a health condition in the population (WHO, 2018). It can be defined by the number of deaths due to a health condition, multiplied by the standard life expectancy at the age at which death occurs.

$$YLL = N \times L$$

Where:

N = number of deaths due to an illness
L = standard life expectance at the age of death in years

Years lost due to disability

The Years Lost due to Disability (YLD) represent the amount of healthy years lost for people living with the health condition or its consequences (WHO, 2018). To calculate YLD, the concept of Disability Weights (DW) is used. The DW reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead), based on individuals' perceptions of the impact of the disease on people's lives (Institute for Health Metrics and Evaluation, 2013). YLD is calculated by multiplying the number of prevalent cases by the disability weight (Institute for Health Metrics and Evaluation, 2013). This is an update of the previous definition of YLD, which was based on *incidence*, rather than *prevalence*.

$$YLD = P \times DW$$

Where:

P = number of prevalent cases
DW = disability weight of illness

Table 74 illustrates the most recent disability weights associated with a number of illnesses. The same disability weights are used for everyone living a year in a specified health state (WHO, 2018). The most recent disability weights are determined using data gathered from thousands of respondents from all over the world, rather than expert judgement.

Table 74 - Examples of disability weights

Disease	Disability weight
Cancer: diagnosis and primary therapy	0.294
Cancer: terminal phase: without medication	0.519
Stroke: long-term consequences, moderate	0.076
Acute myocardial infarction: days 1-2	0.422

Source: Based on (Salomon et al., 2012).

Disability-adjusted life year

One Disability-Adjusted Life Year (DALY) can be defined as one lost year of 'healthy' life, and is the sum of YOLL and YLD due to a health condition. The sum of DALYs across a population is the burden of disease, and can be thought of as a measure of the gap between the current health status and the ideal health status of the population (Institute for Health Metrics and Evaluation, 2013).

$$DALY = YLL + YLD$$

Quality-adjusted life year

Quality-Adjusted Life Years (QALY) have the underlying assumption that health is a function of the length and quality of life. One QALY equals one year of life in perfect health. By multiplying the utility weight[46] associated with a given health state by the years lived in that health state, the QALYs can be calculated (NICE, 2018). E.g. if medical treatment improves a patient's utility from 0.9 to 1, and the person has 10 life years left, then the health gains are equal to one QALY: 0.1 QALY per year over 10 years. The utility value is based on individual perception of their health status on well-being. In general, the relationship between a QALY and a DALY can be summarised as follows, 1 DALY is equal to 1.087 QALY (Sassi, 2006; CE Delft, 2017). Based on (CE Delft, 2017) conservative estimates show that a VOLY (A.2.3) is roughly equal to a DALY, although there are some indications that a DALY should be valued higher than a VOLY.[47] Therefore, one can conclude that a QALY is also roughly equal to a VOLY.

A large study conducted on behalf of the European Commission investigated whether the theoretical assumptions underlying the QALY could be validated by an experiment eliciting respondents' preferences (Beresniak, et al., 2015). The results suggested that most critical

[46] The utility weight and disability weight are inversely related concepts. For instance, if the disability weight is 0.33, then the utility weight is 1 - 0.33 = 0.67.
[47] Please see (CE Delft, 2017) for a full discussion.

assumptions underlying the QALY could not be validated. For instance, responses indicated that individuals are not risk neutral, that willingness to gain or lose life-years is not constant over time, that life-years and quality of life are independent of each other and that the quality of life cannot be measured in consistent intervals (Beresniak, et al., 2015). Other weaknesses of QALYs are that they can only measure the effects of long term care to a limited extent, and that mortality is not part of the QALY, which complicates its use in quantifying external effects.

A.2.2 Valuation of health - Value of a statistical life

Definition

The Value of a Statistical Life (VSL) is also known as the Value of a Prevented Fatality (VPF). There are two main ways in which the VSL can be calculated: labour market studies or willingness-to-pay (WTP) studies. In general, US estimates of the VSL are based on wage risk studies, whereas it is more common in Europe to calculate the VSL based on WTP. The VSL is the amount of money that a community of people are willing to pay to lower the risk of an anonymous instantaneous premature death within that community. It can be calculated by dividing the amount people are willing to pay by the change in mortality risk.

Labour market studies or wage risk studies in particular identify the amount of financial compensation needed to accept a job with a higher mortality rate. This serves as the basis for the calculation of the VSL. In general, a VSL that is calculated based on wage risk studies is much higher than a VSL calculated based on WTP studies. For instance the current recommended VSL is € 6.9 million ($ 9.2 million) in the U.S. and € 4.1 million in Canada (partly based on WTP and partly on labour market studies). European VSLs, based on WTP methods, are more commonly found in between € 1-2 million. There are indications that labour market studies tend to overestimate the VSL because of the cognitive bias in individuals to overestimate small risks and underestimate large risks.

Literature

For a good overview of different VSL studies up to 2007 we refer to (Andersson & Treich, 2009). For a more recent overview of VSL values we refer to (Ecoplan, 2016) (and Table 75 below).

Table 75 – Overview of VSL studies

Study	Country	Calculated for	VSL	Source
Non-European multi-country studies				
OECD	All OECD countries	All areas	$ 3 million (€3.6 million)	Meta-analysis
European VSL studies				
ExternE (2005)	Europe	Air pollution	€ 1 million	Own study
CE Delft (2008)	Europe	Traffic accidents	€ 1.5 million	HEATCO
(HEIMTSA, 2011)	Europe	Health	€ 1.65 million	Alberini (2006)
CE Delft (2011)	Europe	Traffic accidents	€ 1.67 million	UNITE
Ricardo et al (2014)	Europe	Traffic accidents on streets	€ 1.7 million	HEATCO
Ricardo et al (2014)	Europe	Air pollution	€ 1.65 million	HEIMTSA
WHO HEAT (2014)	Europe	Health benefits	€ 3.4 million	OECD

Study	Country	Calculated for	VSL	Source
Single country VSL studies				
Department for Transport (2007)	Ireland	Traffic accidents on streets	€ 1.3 million	Charty et al. (1999)
Abellan Perpinan et al. (2011)	Spain	Traffic accidents on streets	€ 1.3 million	Own study
(Österreichischer Verkehrssicherheitsfonds & BMVIT, 2012)	Austria	Traffic accidents on streets	€ 2.32 million	HEATCO
Sachstandpapier Luft (2012)	Germany	Air pollution	€ 1.65 million	HEIMTSA
(DfT, 2012)	United Kingdom	Traffic accidents on streets	£ 1.1 million (~ € 1.4 million)	Charty et al. (1999)
Norwegian Ministry of Finance (2012)	Norway	All areas	30 million NOK (~ € 4.0 million)	Own study and OECD
(Commissariat général à la stratégie et à la prospective, 2013))	France	All areas	€ 3.0 million	OECD
(Intraplan & Planco, 2014)	Germany	Traffic accidents on streets	€ 1.3 million	HEATCO
(SWOV, 2014)	Netherlands	Traffic accidents on streets	€ 2.0 million	Own study
(Trafikverket, 2015)	Sweden	Traffic accidents on streets	22.3 million SEK (~ € 2.4 million)	Own study

Source: Based on (Ecoplan, 2016).

Table 75 presents an overview of the main studies that have recently been published. The table consists of values from country-specific studies, as well as broader European studies. The most recent, high quality meta-analysis was conducted by the (OECD, 2012). The (OECD, 2012) study is the largest meta-analysis of stated preference VSL studies to date and uses 261 VSL values from 28 studies conducted in OECD countries. The recommended VSL for OECD countries is $ 3 million (range: $ 1.5-4.5 million, 2005 prices), and the recommended EU27 value is $ 3.6 million (2005 dollars), with a range of $ 1.8-5.4 million. This EU27 value is based on 16 European studies in the OECD meta-analysis. However, because this value is elicited from a narrower base, it is arguably more uncertain. For those reasons (Ecoplan, 2016) recommend using the OECD country value of $ 3 million and adjusting it to individual country situations. If we use the OECD value it translates to an EU28 VSL of € 3.6 million (2016 prices). The OECD study was published before the previous edition of the Handbook, yet its values were not used. This was because “the OECD meta-analysis only reports an EU-wide VSL figure and does not include values for each Member State”. Although this is true, the OECD study does provide guidance on how country specific values for the VSL can be calculated.

As Table 75 shows, studies have calculated the VSL values for different circumstances, such as a life lost through air pollution, a traffic accident, during sports or household work. Some scholars have argued that a life lost under one circumstance (e.g. traffic accident) should not be valued the same as a life lost under a different circumstance. For instance, (B,S,S. Volkswirtschaftliche Beratung AG, 2015) conducted a stated preference study with 3000 respondents and identified a VSL of 4.5 million CHF, 30.6 million CHF and 10.5 million CHF for lives lost in road traffic accidents, rail traffic accidents and lives lost due to noise or air pollution respectively. In the past, a VSL identified in one context was frequently used in a completely different context using benefits transfer methods, for instance (Keall, et al., 2011) use the same VSL to value road traffic accidents and accidents that occur at home. A study conducted by (Dekker, et al., 2011) carried out a meta-analysis of 26 international stated preference studies looking at the VSL, and found that the road safety VSL should be multiplied by a factor 1.8 before being applicable in the context of air pollution. This roughly echoes the findings from (B,S,S. Volkswirtschaftliche Beratung AG, 2015). The underlying reason for the different VSL values is due to different risk contexts, such as risk perception and the population at risk. Contrastingly, the meta-analysis carried out by the (OECD, 2012), revealed that the VSL from transport related risk is larger than the VSL from environmental risks, although this difference was not significant. Other studies since, such as (Ecoplan, 2016), build on the OECD results, and therefore recommend the use of the same VSL for lives lost under any circumstance. This is also the recommendation in this Handbook.

It is important to note that the VSL is not constant over one's lifetime (Aldy & Viscusi, 2004); (Carlsson, et al., 2010). Its value peaks around the age of 30-50, after which it starts to decline. There are a number of factors that contribute to this phenomenon. A higher education and a higher income positively contribute to a higher valuation of the VSL, both of which tend to rise (to some extent) with age. In addition, adults are valued most highly because of the important role they have in the family and society, in terms of caring for children and the elderly. (Aldy & Viscusi, 2004) show that the VSL of a 60-year-old is roughly half of the VSL of a 30 or 40-year-old. This echoes the trend in life expectancy. The life expectancy of a 60-year-old is half of the life expectancy of a 30-year-old. Another issue related to age and the VSL is how to value the lives of children. Carlsson, et al., (2010) show that the VSL of children is valued 1.4 times higher than the VSL of 35 to 45-year-old adults, and 3.3 times higher than the VSL of 65 to 75-year-olds. Studies such as (Ricardo-AEA, TRT, DIW Econ & CAU, 2014; HEIMTSA, 2011; UBA & IER, 2014) recommend adjusting the VSL by a factor 1.5 to reach the VSL for children. In Norway, the VSL of children is valued at twice the regular VSL.

In this Handbook, we use the VSL based on the OECD meta-analysis, with a value of € 3.6 million for the EU28. We do not differentiate it to different age groups in this study, although we do recommend the use of an age differentiated VSL if detailed data on e.g. the age of accident victims is available.

A.2.3 Valuation of health - Value of a life year

Definition

The Value of a Life Year (VOLY) is sometimes known as the Value of One Year Lost. The VOLY is the amount of money that people are willing to pay for one year of additional life expectancy (CONCAWE, 2006). Arguably, the VOLY is the correct metric to use in circumstances of non-instantaneous death (IER, 2004) (EC, 2005). In theory the VOLY is related to the VSL, as the VSL can be seen as a discounted sum of annual VOLY-values (CE Delft, 2018).

$$VSL = VOLY \sum_{i=a}^{T} \frac{aPi}{(1+r)^{i-a}}$$

Where:
T = the maximum life expectancy (110 years)
a = average age of the person whose VOLY we are interested in (40 years)
aPi = probability that a person of age *a* will reach age i
r = discount rate

The precise relationship between the VOLY and the VSL is hard to pinpoint as they measure fundamentally different things. The VSL attaches a monetary value to an instant death, whereas the VOLY measures the value attached to one additional year of life expectancy. The VOLY is a proxy for the valuation at the end of one's life, whereas the VSL represents the valuation in the middle of your life. It is therefore not surprising that the literature does not reveal a fixed relationship between the VSL and the VOLY. The relationship is not linear in the sense that one cannot take the average life expectancy and multiply it by the VOLY to reach the VSL. As both the VSL and the VOLY values are based on meta-analysis of studies looking at the individual measure in question, it would be unwise to link the two together as they measure fundamentally different things.

Literature

The literature has suggested a range of different values for the VOLY, of which an overview is provided in Table 76. VOLYs are presented in original prices as well as 2016 prices, where corrections for inflation and growth in GDP per capita were made.

Although the VOLY can be directly derived from the VSL as mentioned in the section above, there is a debate on whether or not that is appropriate in certain contexts. For valuing the life-years of instantaneous deaths, using a VOLY derived from the VSL is logical, as the VSL is elicited based on changes in mortality risk. For non-instantaneous mortality, using a VOLY directly derived from the VSL is arguably comparing apples and oranges. For instance, the NEEDS project argues that VOLYs derived from the VSL overestimate the WTP to reduce health impacts of air pollution and noise. Therefore, the NEEDS VOLY frames the WTP questions to elicit the value of a change in *life expectancy*, rather than a change in *mortality rate*. For non-instantaneous deaths (e.g. deaths as a result of air pollution), this is a better method because air pollution affects the life expectancy, rather than the mortality rate. The NEEDS project recommended a VOLY of € 40,000, with € 25,000-€ 100,000 (2006 prices) as confidence intervals (NEEDS, 2006b; Desaigues, et al., 2011). This value is based on surveys conducted in France, Spain, the UK, Denmark, Germany, Switzerland, Czech Republic, Hungary and Poland, with a total sample size of 1,463.
The previous edition of the Handbook (Ricardo-AEA, TRT, DIW Econ & CAU, 2014) uses (and updates) the NEEDS value (€ 43,000 in 2010 prices, range € 27,000-€ 130,000).

Table 76 – Overview of the VOLY values found in the literature

Study	Year	Country/ region	VOLY in original prices	Price level	VOLY in 2016 prices[48]	Source
NewExt	2004	Europe	€ 50,000	2004	€ 77,800	Own study
ExternE	2005	Europe	€ 50,000	2005	€ 73,700	NewExt
NEEDS	2006	Europe	€ 40,000	2006	€ 55,200	Own study
CE Delft	2008	Europe	€ 50,000	2002	€ 84,900	NewExt, ExternE, NEEDS
European Commission	2009	Europe	€ 50,000-100,000	2009	€ 64,800-129,600	Range of studies
CE Delft	2010	Netherlands	€ 55,000	2008	€ 88,500	Range of studies
HEIMTSA	2011	Europe	€ 90,000 (€ 60,000-220,000)	2010	€ 110,700 (€ 73,800-270,600)	Own research
CE Delft	2011	Europe	€ 44,800	2008	€ 55,700	HEATCO
Concawe et al.	2012	Europe	€,9.000-13,000	2012	€ 10,100-14,600	NEEDS
Quinet et al.	2013	France	€ 115,000	2010	€ 141,400	OECD
Holland	2014	Europe	€ 135,000 (mean) € 58,000 (median)	2005	€ 199,100 (mean) € 85,500 (median)	NewExt
Chanel & Luchini	2014	France	€ 140,000	2001	€ 250,400	Own research
Ricardo-AEA et al.	2014	Europe	€ 43,000	2010	€ 52,900	NEEDS
CE Delft	2017	Netherlands	€ 70,000 (€ 50,000-€ 100,000)	2015	€ 71,900 (€ 51,400-102,700)	Range of studies

Similar values are presented in (ExternE, 2005), where a value of € 50.000 per VOLY (2005 prices) is recommended. (HEIMTSA, 2011) advises values that are higher, in the range of € 60,000-€ 90,000 (2010 prices). The VOLY-value used by the European Commission for health damages as a result of environmental pollution in the impact assessment reports is € 50,000-€ 100,000. Likewise, VOLY values are recommended in (CE Delft, 2017) ranging from € 50,000-€ 100,000, with a central value of € 70,000 (2015 prices). The French government recommends a VOLY of € 115,000 (2010 prices) for use in cost benefit analysis (Quinet et al., 2013). Slightly higher values are presented in (Holland, 2014), where the median and mean VOLY values are € 58,000 and € 135,000 respectively (2005 prices). However, it should be noted that the values mentioned in (Holland, 2014) are based on (NewExt, 2004), where the willingness to pay was elicited from questions framed around changes in mortality rate, rather than changes in life expectancy. This is not appropriate if the VOLY is used for non-instantaneous deaths.

Other literature has presented us with values both near the lower end of the confidence interval, as well as near the higher end. It has, for example, been argued that the distribution of VOLY-values elicited from stated preference studies is broadly spread and skewed, which implies that using the mean or median values is not a robust approach. A 'maximised societal revenue' value is arguably better (Concawe et al., 2012). This approach proposes a simple flat fee, where only those who express a WTP that is

[48] Adjustments were made for inflation and growth in GDP per capita, using an income elasticity of 0.8.

higher than or equal to the fee would need to pay. The flat fee is chosen so as to maximise the revenue from the survey population. The total revenue of the fee becomes the VOLY. The major advantage of this method is that it takes into account the full distribution of expressed WTP values and is less sensitive to extremes. This method results in VOLY-values between € 9,000 and €13,000 (2012 prices), considerably lower than other values.

Recent criticism of stated preference studies revolves around the fact that estimates are an underestimation of the true value if they only take the effect on one's own life expectancy into account (Mouter & Chorus, 2015). In France, a WTP study revealed that many people want cleaner air, not only for themselves but also for friends and family (Chanel & Luchini, 2014). If the effects on loved ones is also taken into account, the VOLY could increase to € 140,000 in 2001 prices (Chanel & Luchini, 2014).

Furthermore, studies have shown that the method with which the study is administered affects the height of the valuation. Questionnaires administered via websites lead to 3-5 times lower values than questionnaires that are administered face-to-face (Istamto et al., 2014). Furthermore, in general discrete choice experiments lead to a higher VOLY-value than WTP studies (such as NEEDS) (Bijlenga, et al., 2011).

Taking all of the above into consideration, our literature review has revealed that an EU28 VOLY of € 70,000 (2016 prices) is not unreasonable. Excluding outliers we can see two peaks in the distribution of VOLY values. The first peak around € 65,000 and the second peak around € 130,000. As we know that the distribution of values for the valuation of health is skewed, with median values lower than the mean values, we propose the use of € 70,000 (2016 prices) as a central EU28 VOLY. We will adjust this EU28 VOLY to national VOLYs, the same way we do for the VSL.

A.3 Recommended approaches

In this Handbook we apply an EU28 average VSL of € 3.6 million (2016 prices), which we differentiate to the country level, following (OECD, 2012). The EU28 VOLY is € 70,000 (2016 prices). We differentiate both values to the individual country level. For a full list of VSL and VOLY values for each country we refer to the database.

B Detailed assessment accident costs

B.1 Introduction

This annex presents more information on how to calculate accident costs, supplementing Chapter 3. First we discuss the components of accident costs in more detail in Section B.2. Section B.3 explores the total and average accident costs in more detail, describing the approach in the previous Handbook and examining new evidence and providing updated values. Lastly, Section B.4 provides an updated assessment of marginal external accident costs.

B.2 Detailed discussion on accident cost elements

Accidents occur in all forms of traffic, both within and between traffic modes, as well as between the same or different vehicle types. In recent years, considerable attention has been placed on reducing the number of accidents in the EU. This is particularly true for road accidents, where the European Commission adopted the ambitious Road Safety Programme. Although the prevalence of accidents has generally fallen in recent years, the costs of accidents still constitute a substantial part of the total external costs of transport.

Although there is no harmonised definition of *external* accident costs, we define them as the social costs of traffic accidents that are not covered by risk oriented insurance premiums in this edition of the Handbook. The insurance system therefore determines the share of the accident costs that are considered internal. Economic theory suggests that for true internalisation of external costs to happen, the marginal costs should be paid for by the causer of those external costs. However, most insurance policies are not, or are only slightly based on the driven kilometres. Furthermore, insurance policies are only somewhat based on risky driving, as the insurance premiums only increase after an accident has happened. Therefore, arguably insurances can only be seen as a way to *partly* internalise the external costs (VU, 2005). Some studies at the national level therefore argue that costs that are insured, should not be considered fully internalised (CE Delft & VU, 2014). However, to fully assess which part of the insured costs are internal and external, a lot of detailed data on national insurance schemes is needed, which is currently unavailable at the European level. Therefore, this Handbook considers costs that are insured as fully internalised.

There are five main components of accident costs:
- *Human costs:* This is a proxy for estimating the pain and suffering caused by traffic accidents in monetary value. Traffic participants are assumed to internalise their own human costs, but they consider the human costs of others as external.
- *Medical costs:* These are the costs of the victim's medical treatment provided by hospitals, rehabilitation centres, general practitioners, nursing homes, etc. as well as the costs of appliances and medicines. This Handbook assumes 50% of the medical costs are external.
- *Administrative costs:* These are the costs covering the expenses of the deployed police force, fire service and other emergency (non-medical) services that assist at the crash location site. This Handbook assumes 30% of the administrative costs are external.

- *Production losses:* These costs represent the lost output per casualty, due to reduced working time (hospital stay and revalidation) and the human capital replacement costs. This component is assumed to be partly internalised by traffic participants through insurance.
- *Material damages:* This consists of the monetary value of damages to vehicles, infrastructure, freight and personal property resulting from accidents. This component is assumed to be fully internalised by traffic participants through insurance.
- *Other costs:* This category covers all other costs not incorporated into any of the above categories. It includes, amongst others, the costs of congestion, vehicle unavailability and funeral costs. These costs are assumed to be fully internalised by traffic participants.

There are three main ways to allocate the total external accident costs (the sum of the aforementioned components) to the different vehicle categories. This can be done based on the responsibility perspective, the monitoring perspective or the damage potential perspective.

- *Monitoring:* The monitoring perspective involves allocating the casualties of an accident to the vehicle type they were using when the accident occurred. In case of an accident between a car and a truck where two individuals seated in the car die and the truck driver sustains an injury, the two fatalities would be allocated to the car and the injury would be allocated to the truck. This is the classic way in which accident statistics are reported.
- *Responsibility:* The responsibility perspective involves allocating the costs of the accident to the party responsibly for causing the accident. This method would imply that if the truck in the above example was responsible for causing the accident, both fatalities and the injury would be allocated to the truck. No costs would be allocated to the passenger car. This is arguably the fairest way to allocate the accident costs. Unfortunately, accident statistics at the EU level do not contain information on responsibility, although some national databases do (e.g. Germany).
- *Damage potential:* This perspective involves allocating all victims in a certain vehicle to the other vehicle involved in the accident. This approach is favoured over the other two methods for two reasons. Firstly, the accident statistics with differentiations on responsibility are not available for all countries within the scope of this study. Secondly, as argued by (CE Delft & VU Amsterdam, 2004) the ‘responsibility’ for an accident in a moral and causative sense does not only lie with the party ‘in error’, but may also lie with the party that, legally speaking, did not commit an error at al. After all, certain activities undertaken by society are accompanied by a certain intrinsic risk, even if no ‘error’ was made. Thus, even if vehicle drivers comply to traffic regulations, there is still the mutual danger to which drivers continually expose each other. The heavier and faster a vehicle, the bigger its damage potential, as it exposes other road users to greater danger. In our example, the costs of the two fatalities that fell in the car would be allocated to the truck, and the injury in the truck would be allocated to the car.

This study employs the intrinsic risk perspective for accidents occurring within road transport. For accidents between different modes, such as accidents involving a train and a car, the casualties are allocated according to the responsibility perspective. In this study, these types of accidents only occur between road and rail, at level crossings. For these types of accidents it is known that they are almost always caused by the road user (Jonsson & Björklund, 2015).

B.3 Assessment of total and average accident costs

B.3.1 Recommended approach previous Handbook

The first Handbook calculated average external accident costs using a top-down approach by multiplying accident statistics per vehicle type by the unit cost per accident and a factor representing what percentage of the unit costs were considered external. The unit cost per accident was based on cost allocation to different vehicle categories from a causation perspective. The percentage of the costs that are considered external was based on information from the insurance system. The 2014 Handbook only looked at marginal costs.

The previous Handbooks use the VSL as a proxy for the human costs. Fatalities were valued at the full VSL. Serious injuries were valued at 13% of the VSL, and slight injuries were valued at 1% of the VSL.

Direct and indirect economic costs for fatalities were valued at 10% of the VSL. These costs were considered fully external. Furthermore, both previous editions of the Handbook did not calculate the total and average costs of IWT accidents and maritime accidents.

B.3.2 New evidence

In general, the major new source of literature since the last edition of the Handbook is the SafetyCube study (Wijnen, et al., 2017). SafetyCube collected information on the national methods to estimate accident costs in 31 European countries to be able to provide crash cost estimates at the country level. For each of the cost components, the method of calculation was checked against the recommended international guidelines created in (Alfaro, et al., 1994). Value transfer was conducted to fill in gaps (for countries that did not measure certain cost components) or to estimate comparable values according to the international guidelines (for countries that did not apply the recommended methods).

According to international guidelines for estimating costs of road crashes (Alfaro, et al., 1994) (Wijnen, et al., 2017) there are three types of methods that can be used to estimate the costs of road crashes. Each of the components of accident costs outlined above can be estimated using one of these three methodologies, which are described below.

- **Restitution costs (RC) approach:** This approach identifies the costs of the resources that would be needed to restore accident victims and their families and friends to the situation where the accident hadn't happened. In general, these costs can be interpreted as the direct costs from a crash, such as the costs of medical treatment and vehicle repair (ERSO, 2006). This is the appropriate method to estimate medical costs, material damages and administrative costs according to international guidelines.
- **Human capital (HC) approach:** This approach measures the value for society of the productive capacities that are lost in road accidents. This is usually based on the added value that a person produces for society. This is the appropriate method to estimate production losses according to international guidelines.
- **Willingness to pay (WTP) approach:** This method estimates costs based on the amount that individuals are willing to pay for a risk reduction. Based on WTP studies, the value of a statistical life (VSL) can be estimated, which can be used to calculate human costs (or risk value) of fatalities. As there is no market price for immaterial impacts such as the risk value, this method is the appropriate method for calculating the risk value.

As we assume that material damages and other costs are fully internalised through relevant insurances (see Chapter 3) we will not discuss them in detail in this section.

Human costs

Using a willingness-to-pay (WTP) approach is generally acknowledged to be the most theoretically sound approach in estimating human costs. It is both recommended in international guidelines for accidents (Wijnen, et al., 2017; Alfaro, et al., 1994), as well as considered good practice in European studies (HEATCO, 2006) and national studies (Wijnen & Stipdonk, 2016) investigating accidents. In WTP studies respondents are asked how much they are willing to pay for a reduction in the risk of being in a fatal traffic accident.

Fatalities

Two approaches can be used to determine the willingness to pay for a reduction in the risk of getting killed in an accident, the 'stated preference' (SP) method or 'revealed preference' (RP) method. The results of either study can be used to derive the VSL, the value attached to a (prevented) fatality. The difference between RP and SP studies is that RP values risk reductions on the basis of actual behaviour, such as through the purchasing decisions of safety provisions (e.g. airbags, seatbelts). In SP methods, questionnaires are presented to individuals, in which they are asked directly or indirectly how much they are willing to pay for safety, from which a VSL can be deduced (see Annex A).

The most recent literature, e.g. (Wijnen, et al., 2017) recommends the SP method as the most appropriate and scientifically sound approach to estimate the VSL in the context of road safety. One of the main advantages of the SP method is that it is not dependent on information on actual consumer behaviour, and therefore can be applied more broadly than RP. As consumers are usually not fully aware of the risk reduction resulting from safety devices, SP provides an edge over RP. This is because the former allows for the provision of this information, helping respondents to understand (small) risk reductions in the correct manner. These above reasons explain why SP methods are most commonly used in the context of road safety in Europe. In regions outside of Europe, particularly in North-America, RP methods are more commonly used (Lindhjem, et al., 2010). A more detailed discussion on the advantages and disadvantages of SP can be found in (De Blaeij, et al., 2003).

It is important to note that literature on the VSL takes a cautious approach and assumes the VSL that elicited from people's WTP for safety includes both human costs and the future consumption that is lost when people abruptly lose their life. Therefore, to avoid double counting with gross production loss (gross production loss consists of net production loss and consumption loss), the consumption loss needs to be subtracted from the VSL to reach human costs, or net production loss (instead of gross production loss) should be used.[49]
In this study we subtract the consumption loss from the VSL to avoid this double counting. The consumption loss of fatalities that we use in our calculations is based on the number of life years lost and annual (market) consumption from Eurostat.[50]

49 See section on production loss in Section B.3.2 for more information.

50 Eurostat data reveals that the average age of someone sustaining an injury in a road accident is roughly 40. In the EU28 a person aged 40 in 2016 is expected to live for another 42 years. The average consumption expenditure per capita in the EU was € 15,900 in 2016. Therefore, the consumption loss of a fatality in the EU28 can be calculated by multiplying the annual consumption loss with the number of life years lost (€ 15,900 * 42 years = € 667,800). This consumption loss needs to be deducted from the EU28 VSL to reach the EU28 human costs of a fatality (€ 3.6 - € 0.7 = € 2.9 million). This exercise is carried out with consumption expenditures differentiated to the national level, resulting in human costs at the national level.

Although the international guidelines recommend the use of WTP to calculate human costs, it is important to note that there are numerous other approaches (e.g. (World Bank, 2005)). Such approaches are, for instance, based on the financial compensation that is awarded to (the relatives of) road casualties in courts or by law (statutory values), the public expenditures on improving (road) safety or the premiums people pay for life insurance. Although there are countries that use such approaches to estimate human costs, these methodologies have severe limitations. The main limitation is the fact that they are not based on the valuations of the road users themselves, which conflicts with economic welfare theory. This is the reason why the WTP method is recommended in international guidelines (Wijnen, et al., 2017; Alfaro, et al., 1994), and why it is used in the majority of studies into the cost of accidents, such as (Wijnen & Stipdonk, 2016; HEATCO, 2006; Infras, CE Delft, ISI & University of Gdansk, 2008; Ricardo-AEA, TRT, DIW Econ & CAU, 2014).

In this Handbook we follow the international guidelines and use the WTP approach to estimate the VSL, which is an input for the human costs of fatalities. We deduct the consumption loss from the VSL to reach the human costs of fatalities (see paragraph on production loss). In line with earlier editions of the Handbook, we assume that drivers completely internalise their own (potential) human costs, but that the human costs of the other traffic participants are 100% external to them (see Chapter 3).

Injuries

The WTP approach can not only be applied to the human costs of fatalities, but also to calculate the human costs of injuries. However, it must be noted that because of the diversity in severity and duration of the consequences of injuries, the human costs of injuries can be very diverse (CE Delft, 2016; InDeV, 2016). A simple way to express the human costs of injuries is as a percentage of the VSL. This was first developed in (HEATCO, 2006) and (UNITE, 2003), where human costs were assumed to be 13% of the VSL for serious injuries and 1% of the VSL for slight injuries.

For an overview of the percentages of VSL that the literature recommends for different injury categories, we refer to the table below, which is based and builds on (Sommer, et al., 2007). It is important to note that direct comparisons between most studies are not ideal, because many studies differ in their definition of a 'serious' or 'slight' injury. The table shows more detailed injury categories than we use in this Handbook.

Table 77 – Overview of the literature on percentages of the VSL used for serious and slight injuries

Study	Country/ Region	Serious injury with lasting impairment	Serious injury with temporary impairment	Average serious injury	Slight injuries
Finland official	Finland	45.7%		0.5%	0.1%
Finland official	Finland	45.7%		0.5%	0.1%
Sweden official	Sweden			15.4%	0.7%
UK official	UK			11.4%	0.9%
Norway official	Norway	55.2%		16.7%	2.9%
(Jones-Lee 1995)	UK	15.1-87.5%	5.5-23.2%		
(ECMT, 1998)	Europe			13%	1%
(Trawén, et al., 1999)	Sweden	13.3-40.4%			0.5-32.1%
(Persson, et al., 2000)	Sweden	40%	11%	16%	1.5%
(Evans 2001)	UK			11%	0.9%
(Persson 2001)	Sweden	40.4%	13.3%		0.9-1.8%

Study	Country/ Region	Serious injury with lasting impairment	Serious injury with temporary impairment	Average serious injury	Slight injuries
(UNITE 2001)	Europe	32.0%	9%	13%	1%
(Ecoplan, 2002)	Switzerland	32.0%	9%		1%
(Goodbody, 2002)	Ireland			13.9%	1%
(HEATCO, 2006)	Europe			13%	1%
(Sommer, et al., 2007)	Switzerland	32%	3.5-15%		1%
(Hensher, et al., 2009)	Australia	3-5%	0.9-1.2%		0.26-0.32%
(Institute of Transport Economics, 2010)	Norway	51.1%	15.4%		1.8%
(Carlsson, et al., 2010)	Sweden			28.6%	
(DfT, 2012)	UK			13.9%	1%
(Österreichischer Verkehrssicherheitsfonds & BMVIT, 2012)	Austria			13%	1%
(Commissariat général à la stratégie et à la prospective, 2013)	France			15%	2%
(Ministry of Transport, 2013)	New-Zealand			10%	0.4%
(Intraplan & Planco, 2014)	Germany			13%	1%
(SWOV, 2014)	Netherlands			12%	
(Ricardo-AEA, TRT, DIW Econ & CAU, 2014)	Europe			13%	1%
(BfU, 2015)	Switzerland	37.3%	3.5-16.3%		0.4%
(B,S,S. Volkswirtschaftliche Beratung AG, 2015)	Switzerland	33.6%	0.5-3.3%		0.03%
(iRAP, 2015)	Worldwide			25%	
(Trafikverket, 2015)	Sweden			16.6%	0.65%
(Wijnen & Stipdonk, 2016)	Worldwide			10-16%	0.9-1.6%

Source: Based on **(Ecoplan, 2016)**. **(Sommer, et al., 2007)**.

Human costs on the MAIS scale

As mentioned in the textbox in Section 3.2, the EU decided that data on traffic injuries would be collected using a new common definition in 2014. The previous definition distinguished between serious and slight injuries. Since 2014, accident statistics use the MAIS definition, which has 6 categories. MAIS 1 and MAIS 2 roughly correspond to the old definition of a slight injury. MASI 3, MAIS 4 and MAIS 5 roughly correspond to the old definition of a serious injury. MAIS 6 is defined as an unsurvivable injury, and therefore corresponds to the old definition of a fatality.

There is almost no literature available on valuing the human costs of injuries according to the new EU definition. One study that we found looking at the valuation of MAIS categories is (Blincoe, 2015). This study presents an average valuation of quality of life lost to crash victims for all 6 MAIS categories. However, this method is based on QALYs lost through traffic injuries, rather than on the WTP method to approximate the human costs, which is the recommended approach in this Handbook. If one expresses the costs for those categories as a percentage of a fatality (see Table 78), the percentages are shown not to differ significantly from the percentages recommended by the (US Department of Transportation, 2015) for the AIS[51] (last column of Table 78).

To approximate values for the human costs of the traffic injuries based on the new MAIS classification, we express the costs of all other injury categories as a percentage of MAIS 6 (fatality) based on (Blincoe, 2015). We can then use these percentages of the fatality value as a proxy for the other injury categories and apply it to our valuation of the human costs of a fatality (with consumption loss already deducted). The table below shows the human costs of the MAIS injury categories according to this method. Please note that this is a very rough first estimate, which certainly deserved further research in the future.

Table 78 – Overview of human costs for new EU injury definition, EU28 aggregate value

Injury category	Human costs from (Blincoe, 2015) using QALY (in $\$_{2010}$)	Costs as a percentage of a fatality	Human costs based on WTP ($€_{2016}$)	Recommended fraction of VSL recommended based on AIS-scale
MAIS 1	23,241	0.3%	8,724	0.3%
MAIS 2	340,872	4.4%	127,949	4.7%
MAIS 3	805,697	10.4%	302,424	10.5%
MAIS 4	2,037,483	26.3%	764,783	26.6%
MAIS 5	4,578,525	59.1%	1,718,581	59.3%
MAIS 6 (Fatality)	7,747,082	100.0%	2,907,921	100.0%

A second way to measure the human costs of injuries is based on Disability Adjusted Life Years (DALYs). DALYs are a measure for impact of injuries on quality of life that combines impact on mortality (fatalities) and morbidity (injuries). An estimate of the monetary value of a DALY can be made based on the willingness to pay for quality of life (see for example (Bobinac, et al., 2013)) or based on the VSL (see for example (Hirth, et al., 2000)). Studies show that the monetary value of a DALY in the Netherlands can be found in the range of € 60,000-€ 80,000 (RIVM, 2014; RVZ, 2006), although there have also been studies suggesting the value exceeds € 100,000 (RIVM, 2006). The major advantage of the DALY approach is that it takes into account the impact of injuries on quality of life, whereas the WTP studies looking at injuries often use a very limited number of broad injury categories from which the valuation of injuries is elicited. However, to date, the only studies that have used DALYs to calculate the human cost of injuries have been conducted in the US (Blincoe et al., 2014).

For the reasons mentioned above, this Handbook values the human costs of injuries using the WTP method at 13% of the VSL for serious injuries and 1% of the VSL for slight injuries. Although the consumption pattern of an injured person may change for the time that they are injured, it does not completely disappear (unlike for fatalities). Therefore, we do not subtract any consumption loss from the human costs for injured people.

51 Please note the subtle difference between the AIS and the MAIS.

Medical costs

Common international practice uses the restitution cost method to estimate these costs. This method uses the actual costs of medical treatment, such as the costs of ambulance trips, overnight hospital stays and non-hospital treatment. This bottom-up approach to medical costs implies that for each aspect of the medical costs (e.g. ambulance trip, hospital day, rehabilitation centre day, treatment by GP, etc.), data on both the number, and the costs of this aspect is needed (Wijnen, et al., 2017; InDeV, 2016).

In principle, this is relatively straightforward. However, in terms of data requirements this method is very demanding. Data is needed on the number of ambulance and helicopter trips, the length of the stay in hospital, the number of polyclinic visits, the number of visits to GPs and physiotherapists, the number of accident victims admitted to a rehabilitation centre, nursing home or receiving home care, etc. Ideally, this information should be available per injury severity category. Furthermore, cost estimates of each of these aspects of treatment should be available. In some countries, models have been developed to calculate the medical costs of injuries, which include most of these data (e.g. (Polinder, et al., 2016) for the Netherlands).

In (Wijnen, et al., 2017) information on the social medical costs of road crashes in 31 European countries was collected. Subsequently, a standard value for the medical costs is calculated according to the recommended method from the international guidelines. These standard values are € 5,430 for fatalities, € 16,719 for serious injuries and € 1,439 for slight injuries (2015 prices). These costs are the total medical costs. However, part of the medical costs are internalised through health insurance. Unfortunately, there is no EU-wide data available on the percentage of health care costs that are covered by insurance. In the Netherlands, 65% of the medical costs is insured and therefore internalised, whereas 35% is external (CE Delft & VU, 2014). In Switzerland medical costs are 90% external (Ecoplan & Infras, 2014). Due to lack of more detailed EU data on this and the fact that medical costs are a relatively minor cost component, we assume that 50% of the medical costs are internalised, resulting in 50% that is external. To calculate medical costs at the country level we update the costs provided in (Wijnen, et al., 2017) to the 2016 level and apply a PPP correction per country.

Administrative costs

There are four major component of administrative costs: police and fire service costs, insurance costs and legal costs.

The police and fire service costs can be calculated using a bottom-up methodology or a top-down methodology. The bottom-up approach multiplies the costs per unit (e.g. police costs per hour or fire service costs per crash) by the time spent on a crash or the number of crashes. The top-down approach estimates the share of costs related to transport accidents of the total police or fire service costs. This is done using information on police or fire service time spent on transport accidents. Both methodologies are theoretically sound.

The administrative costs for vehicle insurance or health insurance relate to the cost of personnel handling claims, including overhead costs. These costs need to be attributed to transport accidents, because no insurance would be needed if there were no road accidents. The administrative insurance costs can be deduced from insurance branch statistics. Alternatively, the insurance costs can be calculated from the costs that are specifically related to handling insurance claims from traffic accidents. This would be done based on the number of claims and the costs per claim.

Lastly, the legal costs can be estimated using a top-down or a bottom-up approach. A bottom-up approach uses cost per unit (e.g. prosecuted offenders, lawsuit, prisoner) and multiplies it by the number of units. In a top-down approach the proportion of total legal costs (costs of prosecution, lawsuits and imprisonment) is determined based on certain variables (e.g. prosecuted people due to a traffic accidents as a proportion of total number of prosecuted people).

Wijnen, et al., (2017) collected information on the total administrative costs of road crashes in 31 European countries. Based on the recommended methods from international guidelines (Alfaro, et al., 1994), a standard value for the administrative costs was presented for fatalities (€ 6,346), serious injuries (€ 4,364) and slight injuries (€ 1,876) (2015 prices). These costs are the total administrative costs. In this study we look at *external* administrative costs (i.e. the part that is not internalised through insurance). Unfortunately, there is no EU-wide data available on the percentage of administrative accident costs that are covered by insurance. In the Netherlands, 84% of the administrative cost is insured, whereas only 16% is external (CE Delft & VU, 2014). In Switzerland administrative costs are 44% external (ARE, 2018). Due to lack of more detailed EU data on this and the fact that administrative costs are a relatively minor cost component, we assume that 70% of the administrative costs are internalised, resulting in 30% that is external. To calculate administrative costs at the country level we update the (Wijnen, et al., 2017) costs to the 2016 level and apply a PPP correction per country.

Production losses

International guidelines recommend the human capital approach as the appropriate method to calculate the production loss. This implies the market production loss of a casualty can be calculated by multiplying the valuation of production per person per unit of time, by the time that the person is unable to work due to the accident. For fatalities the period of time the person is unable to work due to an accident is the remaining number of productive years until retirement. For injured casualties, the remaining period may vary from a few days of absence at work, to all remaining productive years until retirement in the case of a person becoming permanently disabled as a result of the accident.

One major methodological discussion which arises in estimating production losses is whether actual or potential production losses should be used. It is important to note that potential production losses are commonly used to measure production losses (Wijnen, et al., 2017; Wijnen & Stipdonk, 2016). This implies that the capacity to produce is what is valued, regardless of what someone actually produces. This approach is considered a better measure, because it is not sensitive to macro-economic conditions (e.g. labour markets or unemployment rates). Gross national/domestic product per capita, or income are frequently used as an indication for production losses.

Production losses also encompass non-market production loss, e.g. voluntary work. This loss can be estimated using a shadow price that reflects the value of time (usually based on wages) and information on the time spent on household work, child care, etc. However, adding non-market production losses to potential production losses implies there is a risk of double counting production losses. This is because unemployed people may be more involved in non-market production. It is not usually common practice to explicitly include non-market production losses in these costs.

It is important to distinguish between gross and net production loss. This difference exists because individuals that are killed in an accident cannot consume goods and services anymore, and injured people may temporarily consume less as a result of their injuries. Net production loss can therefore be defined as gross production loss minus consumption loss. It is common practice to use gross production loss as a measure for production loss (Wijnen & Stipdonk, 2016). Therefore, if gross production loss is used in calculating accident costs, consumption loss should be deducted from the VSL used to calculate the human costs. This should be done to avoid double counting the consumption loss.[52]
This habit stems from a cautious approach to the WTP value of the VSL. Since it is not entirely known if individuals take into consideration the fact that if a life ends early their consumption is also reduced, it was always cautiously assumed that individuals did take this into account. A recent Swiss study (B,S,S. Volkswirtschaftliche Beratung AG, 2015) showed that people do not take into account their consumption when reporting their WTP for a VSL. This is an interesting conclusion from the first study of its kind, which suggests there is no need for the deduction of the consumption loss from the VSL, as there is no double counting of consumption loss in the two cost components (human costs and production loss).
The conclusions from the (B,S,S. Volkswirtschaftliche Beratung AG, 2015) study highlight the need for further research to confirm these findings in a broader (international) context.
In this study, we deduct the consumption loss from the VSL, but highlight the importance of further research. If we would not do this, the accident costs per fatality would be roughly 20% higher. It would make no difference in the costs for serious and slight injuries, as we assume that these casualties do not suffer from consumption loss, although their spending habits may change.

In this Handbook, we use gross production loss and base the values on (Wijnen, et al., 2017), where a standard value for the production loss was calculated based on data from 31 European countries. The standard value for production losses of € 655,376, € 43,627 and € 2,669 for fatalities, serious injuries and slight injuries respectively (2015 prices) (Wijnen, et al., 2017). The production loss is considered partly internalised. In a study looking at external costs in Switzerland around 55% of the production loss was considered external (Ecoplan & Infras, 2014). This percentage is also used in this Handbook. To calculate costs of production loss at the country level we update the costs from (Wijnen, et al., 2017) costs to the 2016 level and apply a PPP correction.

B.3.3 Conclusions

The different cost components of accident costs are each calculated using the approach suggested by international guidelines.
- *Human costs:* These costs are calculated based on the WTP value of the VSL. The EU28 VSL is € 3.6 million and is based on the (OECD, 2012) and differentiated to the country level (see Annex A). To reach the human costs, the consumption loss is deducted from the VSL. The consumption loss is based on annual market consumption and life years lost through the accident. Drivers consider all human costs of individuals inside their vehicle as fully internal, but the human costs of individuals in other vehicles as fully external.
- *Medical costs:* These costs are based on values presented in (Wijnen, et al., 2017), which are calculated using the restitution costs method. 50% of the medical costs is assumed to not be covered by insurance and is therefore considered external.
- *Administrative costs:* These costs are based on values presented in (Wijnen, et al., 2017). 50% of the medical costs is assumed to not be covered by insurance and is therefore considered external.

[52] See section on human costs in Section B.3.2 for more information.

- *Production loss:* These costs are estimated using the human capital approach and are based on values presented in (Wijnen, et al., 2017). 55% of the costs of production loss are considered external.
- *Material damage:* These costs are considered fully internalised.
- *Other costs:* These costs are considered fully internalised.

Compared to earlier editions of the Handbook, this Handbook includes a more detailed breakdown of the non-human costs of accidents. In earlier editions they were all grouped and assumed to be 10% of the VSL. However, this edition of the Handbook breaks them down into their individual components and calculates them based on the recommended international guidelines.

B.4 Assessment of marginal accident costs

By entering the traffic the driver of the vehicle exposes himself/herself to the average accident risk. However, each additional vehicle may change the accident risk of other transport users. For instance, each additional vehicle means vehicles are more likely to encounter one another, and therefore have a higher accident risk. Simultaneously, extra vehicles lead to busier roads, which leads to more careful driving or lower vehicle speed. This could lower the accident risk. Therefore, the marginal accident costs may be substantially different from average accident costs (higher or lower), depending on the type of road (motorway, urban or other) and the traffic flow (dense or thin).

Marginal accident costs are only calculated for road transport. Rail, aviation, inland waterway and maritime marginal accident costs are assumed to be equal to the average accident costs, as these modes are scheduled services. This implies that the size of the traffic flow is not a determinant in the accident costs. This is in contrast to road transport where the accident risk is highly dependent on how busy a certain road is.

B.4.1 Recommended approach previous Handbook

Earlier editions of the Handbook calculate marginal external accident costs based on a bottom-up approach. This approach multiplied four factors with each other (traffic volume, risk elasticity, unit cost per accident, and percentage of cost that is considered external). The risk elasticity can be defined as the risk of an additional accident at the actual level of traffic volume.

In the second edition of the Handbook (2014) the aforementioned approach was formalised in the following formula.

$$MC_i^v = r_i^v(a+b+c)(1+E_i^v) - \theta^v r_i^v(a+b)$$

With

$$r_i^v = \frac{X_i^v}{Q_i^v}$$

And

$$E_i^v = \frac{\partial r_i^v Q_i^v}{\partial Q_i^v r_i^v}$$

Where:

$r_i^v =$ The accident risk for each vehicle type (v) and road type (i)
$X_i^v =$ The number of fatality or injury cases for each vehicle type (v) and road type (i)
$Q_i^v =$ The number of vehicle kilometres for each vehicle type (v) and road type (i)

$a =$ The costs due to an accident for the person exposed to the risk
$b =$ The costs for the relatives and friends of the person exposed to the risk
$c =$ The costs of the accident to the rest of society (production loss, material damages, administrative costs, medical costs)
$E =$ The risk elasticity, which reflects how much a 1% increase in traffic (measured in vkms) increases the accident risk in percent
$\theta^v =$ The share of the accident costs that is internal for each vehicle category

(Social) Marginal costs can be expressed as a function of the costs per accident, the accident risk and the risk elasticity. The latter two terms may be dependent on the vehicle and road type, as certain vehicle or road types may be more or less dangerous than others. To reach external marginal costs, the share of the costs that are internal still needs to be deducted from the social marginal costs, this is done in the second half of the formula.

The risk elasticity (E) that was used in the 2014 Handbook was a conservative estimate of -0.25, irrespective of the vehicle and road type. This was based on (Lindberg, 2001; TML, 2010). The degree of risk internalisation (θ) that was used in the 2014 Handbook differs per vehicle type, see table below.

Table 79 - Overview of values used in 2014 Handbook for the degree of risk internalisation for marginal costs

Vehicle type	Degree of risk internalisation	Source
Cars	0.76	(Lindberg et al., 2006)
LCVs and HGV	0.22	(Lindberg et al., 2006)
Buses	0.16	(Lindberg et al., 2006)
Motorcycles	0.8	(Fridstrom, 2011)

B.4.2 New evidence

Very little research has been conducted on marginal accident costs. As a consequence there is little to no new literature on these costs. We therefore use the same formula as identified in the 2014 edition of the Handbook.

For the risk elasticity it was common practice to use the same risk elasticity parameter for each of the road types in the previous Handbooks. The value was -0.25, a value which was not differentiated according to vehicle type or road type (Lindberg, 2001; TML, 2010). This implies an increase in vehicle kilometres of 1% has the same effect on the average accident rate, regardless if this is because of trucks or motorcycles, and regardless of whether it occurs on motorways, urban roads or other roads. Although some authors have argued that the elasticities should be corrected for each vehicle type's traffic share, e.g. (Fridstrom, 2011), such studies have only been carried out at the national level and cannot be generalised to other countries. Similarly, a Swiss study by (Sommer et al., 2002) showed that risk elasticities can be differentiated to road types. For this national study, risk elasticities were found to be -0.5, -0.25 and -0.62 for motorway, urban and other roads respectively. All risk elasticities used in the previous Handbook are negative, implying that an increase in traffic (measured in vehicle kilometres) leads to reduction in the accident risk. This is caused by two opposing effects. Firstly, an increase in traffic exposes more drivers to the possibility of an accident, which should increase the accident rate. However, average traffic speed also decreases with more traffic, which reduces the possibility of an accident. The results from the study by (Sommer et al., 2002; Lindberg, 2001) confirm that the latter effect is larger than the former, implying an increase in traffic leads to a reduction in the accident risk. Arguably in locations where the speed is already slow (i.e. urban roads or congested areas), the latter effect is not likely to outweigh the former. This was argued in (CE Delft & VU, 2014) who use a risk elasticity of 0 for these roads, implying that an extra vehicle does not significantly change the accident risk. In this study we use the risk elasticity of -0.25 for motorways and other roads conform (Lindberg, 2001; TML, 2010; Ricardo-AEA, TRT, DIW Econ & CAU, 2014), and a risk elasticity of 0 for urban roads (conform (CE Delft & VU, 2014)).

For the human costs, $(a + b)$ in the equation presented above, we base our calculations on a different VSL than the 2014 Handbook. The new VSL values are significantly higher than those presented in the 2014 Handbook. A more detailed discussion on the VSL can be found in Annex A.

The degree of risk internalisation can be based on the literature (as was done in the previous 2014 Handbook, see Table 78), but can also be calculated if detailed data on accidents are available. The latter is the approach taken in this Handbook. This approach was developed by (Lindberg, 2001) and assumes that a part of the accident risk is internalised, which can be estimated by dividing the number of fatalities inside a certain vehicle type by the number of fatalities in accidents involving this vehicle type (and therefore also counting victims inside other types of vehicles involved in the accidents). Based on the CARE database, such detailed data is available, and is used to calculate the degree of risk internalisation in this Handbook, which results in the internalisation factors as shown in Table 11.

B.4.3 Conclusions

This Handbook uses the approach as outlined by the 2014 Handbook, but updates the input values that were used in the 2014 Handbook. The VSL used is taken from the (OECD, 2012) (EU28 value of € 3.6 million in 2016 prices) and differentiated to the country level (see Annex A). The other cost components are taken from (Wijnen, et al., 2017). The risk elasticity is set at -0.25 for motorways and other roads, which is identical to the value presented in the previous Handbook and (Lindberg, 2001; TML, 2010), and set at 0 for urban roads, conform (CE Delft & VU, 2014). This value is set to be the same, regardless of vehicle type. The degree of risk internalisation is differentiated to vehicle type, calculated from the CARE database. This accident risk per vehicle type is also calculated based on the CARE database and the transport performance data.

C Detailed assessment air pollution costs

C.1 Introduction

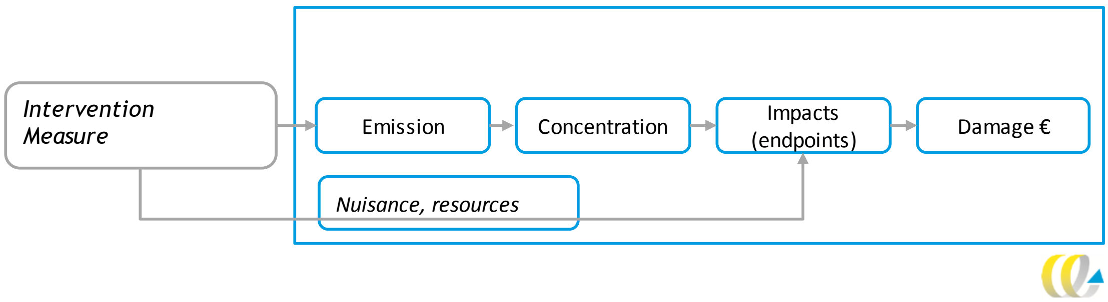
This annex presents more information on how air pollution costs are calculated, giving additional information to Chapter 4.

C.2 Detailed discussion on effects of air pollution

The present Handbook covers the following four types of impacts caused by the emission of transport related air pollutions:
- **Health effects:** The inhalation of air pollutants such as particles (PM_{10}, $PM_{2.5}$), nitrogen oxides (NO_x) and others lead to a higher risk of respiratory diseases (e.g. bronchitis, asthma, lung cancer) and cardiovascular diseases. These negative health effects lead to medical treatment costs, production loss at work (due to illness) and partially even to death.
- **Crop losses:** Ozone as secondary air pollutant (mainly caused by the emission of NO_x and VOC) and other acidic air pollutants (e.g. SO_2, NO_x) can lead to damage of agricultural crops. As a consequence, an increased concentration of ozone and other substances can lead to lower crop yield (e.g. for wheat).
- **Material and building damage:** Air pollutants can mainly lead to two types of damage of buildings and other materials: a) pollution of building surfaces through particles and dust; b) damage of building facades and materials due to corrosion processes, caused by acidic substances (e.g. nitrogen oxides NO_x or sulphur oxide SO_2).
- **Biodiversity loss:** Air pollutants can lead to damage of ecosystems. The most important damages are a) the acidification of soil, precipitation and water (e.g. by NO_x, SO_2) and b) the eutrophication of ecosystems (e.g. by NO_x, NH_3). Damages at ecosystems can lead to a decrease in biodiversity (fauna, flora).

The overall framework adopted for the estimation of the damage cost of pollutants is schematically summarized in the following figure.

Figure 17 - The approach for damage cost calculations: from emission to impact and damage



A given activity leads to emissions. In the case of transport emissions, these emissions are primarily emissions to the air (a certain amount of tyre wear can end up as emissions to soils or water, but these have not been taken into account in this Handbook).
These emissions are subsequently transported through the atmosphere to other regions where they are added to existing emission concentrations. This concentration then leads to changes in 'endpoints' relevant to human welfare. These changes can be monetarily valued by quantifying the amount of damage caused at the endpoints. The entire chain from emissions, nuisance and resources through to damage in monetary terms is the subject of the present Handbook.

C.3 Assessment of air pollution costs in the previous Handbook

The methodological approach applied in the last Handbook has been the same as in the present Handbook, using cost factors per pollutant as input values. The main source for the cost factors in the previous Handbook has been NERI (2010) plus the EU-project CAFE CBA.

C.4 New evidence

The following section gives an overview on the latest literature on different aspects for the calculation of the air pollution costs.

C.4.1 General overview

The updates in the Concentration Response functions have been set up by comparing the NEEDS outcome on the Concentration Response functions with the WHO (2013) recommended values and approaches. This is not straightforward as both studies report different units. Whereas the NEEDS study reports CRF functions, expressed in $\mu g/m^3$, works the WHO with Relative Risks (RR).

Most epidemiological studies report their results in terms of relative risk RR, defined as the ratio of the incidence observed at two different exposure levels. The RR can therefore be interpreted as the increase in percentages in the relative risk in the reported impact due to an increase in exposure levels of $10/\mu g/m^3$. To quantify damages, one needs to translate this RR in terms of a concentration response function, also called exposure response function (Rabl, et al., 2014). For this one needs to know the existing risk on these incidents. So for an RR of 1.046 per $10/\mu g/m^3$ for Working Days Loss due to $PM_{2.5}$ lung diseases, one needs to understand how often the population already is suffering from these diseases.
The CRF can then be regarded as the product of the baseline and the Delta RR.

We have started from the table of health impacts in NEEDS as can be seen in the following Table.

Table 80 – Concentration-response functions and external air pollution costs

Core Endpoints	Pollutant	Risk group (RG)	RGF value	Age Groupe (AG)	AGF value	CRF [1/(µg/m3)]	phys. Impact per person per µg per m3 [1/(µg/m3)]	unit	Monet Val per case or per YOLL [Euro]	External costs per person per µg per m3 [1/(µg/m3)]
primary and SIA < 2.5, i.e. Particle < 2.5µm										
Life expectancy reduction - YOLLchronic	PM2.5	all	1.000	Total	1	6.51E-04	6.51E-04	YOLL	40,000	2.60E+01
netto Restricted activity days (netRADs)	PM2.5	all	1.000	MIX	1	9.59E-03	9.59E-03	days	130	1.25E+00
Work loss days (WLD)	PM2.5	all	1.000	Adults_15_to_64_years	0.672	2.07E-02	1.39E-02	days	295	4.10E+00
Minor restricted activity days (MRAD)	PM2.5	all	1.000	Adults_18_to_64_years	0.64	5.77E-02	3.69E-02	days	38	1.40E+00
primary and SIA < 10, i.e. Particle < 10µm										
Increased mortality risk (infants)	PM10	infants	0.002	Total	0.009	4.00E-03	6.84E-08	cases	3,000,000	2.05E-01
New cases of chronic bronchitis	PM10	all	1.000	Adults_27andAbove	0.7	2.65E-05	1.86E-05	cases	200,000	3.71E+00
Respiratory hospital admissions	PM10	all	1.000	Total	1	7.03E-06	7.03E-06	cases	2,000	1.41E-02
Cardiac hospital admissions	PM10	all	1.000	Total	1	4.34E-06	4.34E-06	cases	2,000	8.68E-03
Medication use / bronchodilator use	PM10	Children meeting PEACE criteria - EU average	0.200	Children_5_to_14	0.112	1.80E-02	4.03E-04	cases	1	4.03E-04
Medication use / bronchodilator use	PM10	asthmatics	0.045	Adults_20andAbove	0.798	9.12E-02	3.27E-03	cases	1	3.27E-03
Lower respiratory symptoms (adult)	PM10	symptomatic_adults	0.300	Adults	0.83	1.30E-01	3.24E-02	days	38	1.23E+00
Lower respiratory symptoms (child)	PM10	all	1.000	Children_5_to_14_years	0.112	1.86E-01	2.08E-02	days	38	7.92E-01
Ozone [µg/m3] - from SOMO35										
Increased mortality risk	SOMO35	Baseline_mortality	0.0099	Total (YOLL = 0.75a/case	1	3.00E-04	2.23E-06	YOLL	60,000	1.34E-01
Respiratory hospital admissions	SOMO35	all	1.000	Elderly_65andAbove	0.158	1.25E-05	1.98E-06	cases	2,000	3.95E-03
MRAD	SOMO35	all	1.000	Adults_18_to_64_years	0.64	1.15E-02	7.36E-03	days	38	2.80E-01
Medication use / bronchodilator use	SOMO35	asthmatics	0.045	Adults_20andAbove	0.798	7.30E-02	2.62E-03	cases	1	2.62E-03
LRS excluding cough	SOMO35	all	1.000	Children_5_to_14_years	0.112	1.60E-02	1.79E-03	days	38	6.81E-02
Cough days	SOMO35	all	1.000	Children_5_to_14_years	0.112	9.30E-02	1.04E-02	days	38	3.96E-01

Abbreviations: Risk Group, RG: group within the general population with a handicap; RGF value: share of RG within the general population; Age group, AG: groups distinguished by different age cohorts; AG value: share of different age cohorts; CRF: concentration-response function; YOLL: Years of Life Lost; RAD: Restricted Activity Days; SIA: Secondary Inorganic Aerosols; SOMO35: sum of ozone means over 35 ppb; WLD: Work Loss Days; MRAD: Minor Restricted Activity Days; LRS: lower respiratory symptoms. Table constructed for the whole of Europe.

Source: NEEDS (2008a), based on NEEDS (2007).

Below for various impact groups the relevance of these CRFs for the present Handbook is discussed in light of the recent WHO (2013) update. First, the mortality impacts are discussed and then the morbidity impacts are identified.

C.4.2 Mortality impacts

Mortality impacts occur because of $PM_{2.5}$, NO_2, and ozone pollution (also called SOMO-35, Sum Of Means Over 35ppb, e.g. the excess of max daily 8-hour averages over 35 ppb which is about 70 µg/m^3).

All-cause mortality $PM_{2.5}$

The HRAPIE experts recommended estimation of the impact of long-term (annual average) exposure to $PM_{2.5}$ on all-cause (natural) mortality in adult populations (age 30+ years) for cost- effectiveness analysis (Group A). A linear ERF, with an RR of 1.062 (95% CI = 1.040, 1.083) per 10 µg/m^3, has been recommended — even though some recent evidence has suggested a RR of 1.066. We observe that these RRs are practically similar to the used RR of 1.06 in the NEEDS project. As the Iref is probably nowadays slightly lower due to better health in population due to healthier lifestyles. *Therefore, our conclusion is that this value will not be altered compared to the NEEDS estimates.*

All-cause mortality SOMO 35

The NEEDS project only includes acute mortality (e.g. heart attack) with an RR of 1.003 per 10 µg/m^3 compared to the normal change of having a heart attack (which was established as 1% of population). The valuation of acute mortality is 50% higher than for chronic impacts. WHO (2013 and 2014) provide insights that there are also chronical components included in ozone pollution. For a population of 30 years old or older, the WHO (2013) recommends adopting a relative risk factor (RR) of 1.014 per 10 µg/m^3 in the summer months (April–September) for 8-hours concentration higher than 35ppb. As explained in Jerrett et al. (2009) (Michael, et al., 2009), this may increase the CRF a factor of 9 compared to the acute impact. This is not only due to the higher RR, but also due to taking a different incidence rate. However, the precise impact is very uncertain. In our model we proposed to use a factor of 3.5 as a lower bound and a factor of 9 as an upper bound, so that the average factor through which the NEEDS outcomes need to be multiplied is equivalent to a factor of 6. *Therefore, it is proposed to include the mortality impacts by calculating them as a factor of 6 higher compared to NEEDS (2008) and by keeping the incidence rate the same (% of population with a heart attack).*

Mortality NO_2

The REVIHAAP project (WHO, 2013) reports that since 2004 a growing number of studies have been published identifying short- and long-term correlations between NO_2 and mortality and morbidity that come on top of the impacts of NO_2 on PM formation and of NO_2 on acute mortality due to ozone formation. There is thus a third category that is not associated with particulate matter formation or ozone formation and that has here been added to the theme of acidification. These have not yet been included in the NEEDS project.

At the time of the NEEDS project these impacts were not included because the team was unable to identify sufficient studies that properly quantified these epidemiological impacts (NEEDS, 2007). Today (2016) the situation has changed and the WHO (2013) recommends adopting a higher CRF for NO_2 than was previously used. The HRAPIE experts (WHO, 2013) recommend including the long-term mortality impacts (all-cause and cardiovascular) of NO_2 and advise adopting a linear CRF for NO_2 for all-cause mortality, translating to an RR of 1.055 per 10 µg/m^3 (WHO, 2013). In this context the WHO (2014) notes that when employing this RR-value in multi-emission studies due care should be taken to avoid double-counting with respect to the impact of NO_2 on PM formation, which they state can be as much as 33%.

To make this double-counting explicit, we examined the contribution of NO_2 to the RR-value for PM formation. For PM, NEEDS (2007) uses an overall RR for premature mortality of 1.06 per 10 µg/m^3. The relative contribution of NO_2 to PM formation can be derived from the characterisation factors.

For characterising NO_2 with respect to PM formation, ReCiPe takes a value of 0.22. This means that 22% of the RR increase can be attributed to impacts already taken into account under the theme of PM formation, equal to an RR of 1.013 per 10 µg/m^3.[53] Assuming, in line with WHO (2014), a linear CRF for NO_2-values over the 20 µg/m^3 threshold, it can be concluded that the additional NO_2 RR-value must be 1.042 per 10 µg/m^3 for pollution in areas above the threshold level. This implies that the chronic health damage

[53] This estimate is feasible because in ReCiPe PM formation is considered only in terms of its impacts on the endpoint ‘human health’.

attributable to NO_2 should be a factor 3 higher than assumed in NEEDS, based on its contribution to PM formation.

To this factor, two additional corrections should be made:
1. The mortality applies only to people older than 30 years.
2. The mortality applies only to population living in areas with an annual mean concentration of pollution above 20 µg/m^3.

C.4.3 Morbidity impacts

For the morbidity impacts we have consulted WHO (2014) and WHO (2013). Below we will discuss first the morbidity impacts of particulate matter, ozone pollution and NO_2.

Morbidity impacts of $PM_{2.5}$ and PM_{10}

Cardiac hospital admissions

The value in Rabl et al. (2014) has been taken. This is taken from Hurley et al. (2005) *and* based on a RR of 1.006 per 10/µg/m^3 PM_{10}. Calculated to $PM_{2.5}$ we use the factor 1.6 as in (CE Delft, 2017), which implies that this would translate itself to a RR of 1.0096 per 10 µg/m^3 $PM_{2.5}$. This in turn is more or less equivalent to the recommended value of 10091 from the WHO. ***Therefore, our conclusion is that this value will not be altered compared to the NEEDS estimates.***

$PM_{2.5}$: Net restricted activity days

The analysis in WHO (2014) is based on the same sources as NEEDS (2008) and Rabl et al. (2016). We use the routine in the EcoSense model where the Restricted Activity Days have been netted by subtracting the working days loss, the minor restricted activity days and the hospital admissions due to $PM_{2.5}$ pollution from the RR from WHO. We have followed this routine and have used the values from the EcoSense model. ***Therefore, our conclusion is that this value will be taken from the EcoSense model.***

$PM_{2.5}$: Minor restricted activity days (MRAD)

This category has not been included in WHO (2014) separately but is added to the net restricted activity days. We follow NEEDS as the valuation of both days differs and our aim is to include this differentiation in our calculations. ***Therefore, our conclusion is that this value will be taken from the EcoSense model.***

$PM_{2.5}$: Working days loss

The approach and data in the NEEDS (2008) project are the same as in WHO (2014, background paper 6). ***Therefore, our conclusion is that this value will not be altered compared to the NEEDS estimates.***

Respiratory hospital admissions

The WHO (2014) reports a RR of 1.019 for the whole population on the basis of a meta-analysis. This is slightly lower than the RR that has been used in the NEEDS project, which would be around 1.022 recalculated on the basis of the factor between $PM_{2.5}$ and PM_{10}. Since these values only differ slightly we have decided not to update this estimate. ***Therefore, our conclusion is to update the NEEDS estimate with the estimate from the WHO (2014).***

Medication use and lower respiratory symptoms because of asthma

These categories relate to the costs of medication and disutility for asthmatic people from additional coughing days. The additional medication use is valued at 1 €/day and the disutility is valued at 38 Euro/day. The recent WHO (2014) update advises to only take impacts on children (age 5-19) into account, reporting a RR of 1.028 for children with asthma. In Europe, on average, 4.5% of the children suffer from asthma. Taking the incidence rate of 17% of the days that they suffer from asthma, the ERF becomes: 0.17*(1.028-1)=0.00476 days. **Our conclusion is to follow the WHO (2014) approach and only use medication use and lower respiratory symptoms for asthmatic children.** The costs have been based on Ready et al. (2004), as quoted in Rabl et al., (2014) where we assumed that every fourth cough day for children leads to an additional visit to the doctor. The medical costs are then calculated as €11/day.

New cases of chronic bronchitis and COPD for adults

WHO (2014) advices to use an RR differentiated between children and adults. The RR for adults is 1.117 and for children 1.08. There is quite some discussion on the basic incidence rate (see e.g. (Hurley, et al., 2005)), but the WHO proposes to use an incidence rate of 18.6% for children and 0.39% of adults. The NEEDS project used an RR of 1.07 per 10/µg/m^3 and an incidence rate of 0.378%. This implies that the new RR is about 70% higher.
We therefore used thus a 70% higher ERF in our modelling. In addition, WHO (2014) advices to use this factor for all population older than 18, whereas NEEDS used this impact only for those 27 and older. **Therefore, our conclusion is that the NEEDS underestimates the recent WHO Guidelines. We have therefore updated our estimates using a 70% higher estimate.** One should notice that the WHO classifies this information with a 'B' label indicating that these impacts are more uncertain than other impacts. We have also decided not to include potential new cases of chronic bronchitis for children (also labelled as 'B', as the unit in which this indicator is not an endpoint in the NEEDS modelling effort).

Morbidity impacts of ozone (SOMO-35)

Hospital admissions

WHO (2014) reports hospital admissions from ozone both for respiratory and cardiac diseases. NEEDS (2008) has only used respiratory diseases. The RR used in NEEDS for respiratory diseases is very similar to the one proposed in WHO (2014). **Therefore, our conclusion is to follow WHO and extend this category by including cardiac hospital admissions.**

Minor restricted activity days

The background studies and assumed RR is the same for NEEDS (2008) and WHO (2014). **Therefore, our conclusion is that this value will not be altered compared to the NEEDS estimates.**

Medication use, lower respiratory symptoms and cough days

These impacts have not been included in WHO (2014). **We propose here to follow WHO (2014) and not include these symptoms in the cost calculations.**

Morbidity impacts of NO_2

Morbidity impacts of NO_2 have not been included in the NEEDS project as scientific evidence was not yet overwhelming as to the chronic impacts from NO_2 pollution. WHO (2013) recommends including these in cost-benefit analyses.

Prevalence of bronchitis in asthmatic children

For calculation of the impacts of bronchitis, we follow the same routine as in the impacts of $PM_{2.5}$ on bronchitis and medication use for asthmatic children (see point F above), assuming a European average of 4.5% of children are being asthmatic. The additional costs of NO_2 pollution is very small.

Hospital admissions respiratory problems.

We follow the same routine as in Hurley et al. (2015) where the estimated baseline of hospital admissions related to respiratory problems is 617 per 100.000 inhabitants.

The CRF and estimated baseline rates can be linked to provide an impact function:
Annual rate of attributable emergency respiratory hospital admissions
= background incidence rate (617/100,000) × change per 10 μg/m^3 NO_2 (1.8%)
= 7.03 (95% CI 3.83, 10.30) per 10 μg/m^3 PM_{10} per 100,000 people (all ages)

Also here, the additional impact of NO_2 on hospital admissions is very small and does not influence the final results.

Outcome health effects

The following table presents the adopted changes from the NEEDS project for the EU population. All cells in green (CRF functions) and orange (population) are adaptations from the original NEEDS project.

Table 81 - Changes compared to the NEEDS project

Core Endpoints	pollutant	risk group (RG)	RGF value	Age Group (AG)	AGF value	CRF [1/ug/m3]	unit
Primary and SIA < 2.5 i.e. Particle < 2,5 um							
Life expectancy reduction - YOLLchronic	PM2.5	all	1	Total	1	6,51E-04	YOLL
netto Restricted activity days (netRADs)	PM2.5	all	1	MIX	1	9,59E-03	days
Work loss days (WLD)	PM2.5	all	1	Beroepsb	0,4131472	2,07E-02	days
Minor restricted activity days (MRAD)	PM2.5	all	1	Adults_18	0,6232605	5,77E-02	days
Primary and SIA < 10 i.e. Particle < 10 um							
Increased mortality risk (infants)	PM10	infants	0,0019	Total	0,0102755	4,00E-03	cases
New cases of chronic bronchitis	PM10	all	1	Adults_18	0,812034	4,51E-05	cases
respiratory hospital admissions	PM10	all	1	Total	1	7,03E-06	cases
cardiac hospital admissions	PM10	all	1	Total	1	4,34E-06	cases
medication use/bronchodilator use	PM10	Children with severe astma	0,045	Children_	0,1046751	4,76E-03	cases
medication use/bronchodilator use	PM10	asthmatic	0,045	Adults_20	0,7907585	0,00E+00	cases
lower respiratory symptoms (adult)	PM10	symptoma	0,3	Adults	0,812034	0,00E+00	days
lower respiratory symptoms (child)	PM10	all	1	Children_	0,1046751	0,00E+00	days
Ozone [ug/m3] - from SOMO35							
Increased mortality risk	SOMO35	baseline_	0,0099	Total (YOL	1	3,00E-04	YOLL
respiratory hospital admissions	SOMO35	all	1	Elderly_65	0,1887735	1,25E-05	cases
MRAD	SOMO35	all	1	Adults_18	0,6232605	1,54E-02	days
medication use/bronchodilator use	SOMO35	asthmatic	0,045	Adults_20	0,7907585	7,30E-02	cases
LRS excluding cough	SOMO35	all	1	Children_	0,1046751	1,60E-02	days
Cough days	SOMO35	all	1	Children_	0,1046751	9,30E-02	days
NO2 [ug/m3] -							
Increased mortality risk	NO2	all	0,28	Adults 30+	0,6690976	4,41E-04	YOLL
Prevalence of bronchitis in asthmatich chi	NO2	all	0,045	Children_	0,1578638	5,25E-03	cases
Hospital admissions due to respiratory dis	NO2	all	1	Total	1	1,11E-05	cases

Abbreviations: Risk Group, RG: group within the general population with a handicap; RGF value: share of RG within the general population; Age group, AG: groups distinguished by different age cohorts; AG value: share of different age cohorts; CRF: concentration-response function; YOLL: Years of Life Lost; RAD: Restricted Activity Days; SIA: Secondary Inorganic Aerosols; SOMO35: sum of ozone means over 35 ppb; WLD: Work Loss Days; MRAD: Minor Restricted Activity Days; LRS: lower respiratory symptoms.

Source: Adjusted from NEEDS (2008a), based on NEEDS (2007) with own recalculations of the green and orange cells.

C.4.4 Impacts on building and materials

The impacts on buildings and materials have been approached in the same way as in (CE Delft, 2017). For the impacts on building and materials we have opted for the high prices scenario, because it is only in this scenario that all impacts of air pollution on buildings and materials have been quantified.

In the Handbook the following four cost categories have been adopted:
1. Corrosion due to acidification. As in (CE Delft, 2010), the corrosive impacts of acidifying emissions on metals, building stone and paint are based on NEEDS (2008a). NEEDS itself derives its prices from maintenance costs per square meter for a number of different materials. These prices have not been adjusted to the slightly higher density of

buildings in 2015 compared with 2000, because we assume this has been offset by use of less corrosion-sensitive materials in buildings (including renovations).
2. Particulate pollution. The impacts of particulate pollution are based on Defra (2006), who in turn derive their calculations from Rabl (1999), who analysed expenditure on restoration of pollution-soiled buildings in fifteen French cities. Applying a regression analysis, Rabl estimated damage costs, defined a CRF-function and calculated damage costs as € 0.21/kg PM_{10} in 1998 prices. This value has been taken as the basis for EU28 restoration costs, correcting for inflation and higher populations resulting in an estimate of € 0.3 for 1 kg PM_{10} in the EU28. It should be noted however that this value holds only for primary particles, because this is the fraction containing soot. For secondary particulates, eventual damage has been set to zero. Given a ratio of ½ for $PM_{2.5}/PM_{10}$, this means the value for $PM_{2.5}$ is € 0.15/kg $PM_{2.5}$.
3. Corrosion impacts on cultural heritage. In line with the British and Belgian Handbooks, impacts on cultural heritage have not been valued using a central value, as the uncertainties are too great. VMM (2013b) states that these are about the same as the restoration costs under category (1). For Paris, Rabl (1999) calculates these to be 62% of the combined restoration costs under (2) and (3). This is in line with the approach adopted in VMM (2013). We have therefore taken this as the upper damage value.
4. Impacts on paint and plastics. For the costs of damage to paint and plastics due to ozone, we adopted the values reported in Watkiss, et al. (2006), who state that paint damage is unlikely to have any major impact as average ozone concentrations are generally too low. According to Watkiss, et al., evidence of such impacts are deriven from mainly from US studies carried out in the late '60s. For damage to rubber materials empirical evidence does exist however. For the UK, a central value of £ 85 million/year has been estimated, with a range from £ 35 million to 189 million (1997 data). If this is compared with total 1997 UK emissions — 2,032 kilo-tonne — this is a modest sum. Since then there has been a further decline in the use of natural rubber, which has been largely superseded by synthetic materials. Given these facts, we opted for a central value based on the CRF-function from the literature underpinning Watkiss et al. (2006), giving a damage figure of € 0.1/kg NMVOC.

For the differentiation of $PM_{2.5}$ emissions we have assumed that the national average is valid for cities and can be doubled in the case of metropoles while no damage can be expected in rural areas.

C.5 Detailed description of the methodology applied

A short overview on the methodology applied to derive cost factors for air pollutants is given in Section 4.3.1. A more detailed description of the methodology is given in the following section.

Since 2009 there has been no further development of NEEDS and neither of the rival model CAFE-CBA (IIASA, 2014). It is also striking is that recent shadow price manuals for Ireland, Belgium and Germany (under development) are still based on the NEEDS methodology owing to its far greater transparency. However, one cannot simply take the NEEDS values and apply them to air pollution because the estimation results are over a decade old and many things have changed: background concentration levels, knowledge about impacts from pollution and the valuation framework. For that reason, adaptations to the NEEDS framework must be made. This is possible since we have the possession of a great deal of modelling outcomes from the NEEDS model so that we can make required changes to reflect more recent insights.

To recalculate cost factors for air pollutants in the present study, five 'adjustments' (i.e. update calculations) were made to the NEEDS results. These adjustments are broadly the same as in the Environmental Pricing Handbook (CE Delft, 2018) but they are now applied to the EU context. These five adjustments can be described as follows:

1. Concentration Response Functions have been adapted to the WHO (2013) study. The taken steps taken are described in more detail below.
2. The population size and population structure (age cohorts) is based on the most recent data from Eurostat.
3. The influence of the background concentration is estimated on the basis of the relationship between damage and emissions for various emission scenarios from NEEDS (2008). On this basis, by letting all other factors remain the same, we can estimate the impact of a change in emissions on the harmfulness of these emissions. This harmfulness is then the result of the change in the background concentration.
4. The valuation has been adjusted to the most recent insights with respect to cost of the physical and health impacts. For human health we refer to Annex A. For the change in valuation of ecosystems and buildings, see Section C.4.4.
5. Finally, a subdivision was made for both $PM_{2.5}$ and NO_2 to the population density (people living in cities or in rural areas have different damage from pollution). For $PM_{2.5}$ a further distinction was made to transport emissions and other sources of emissions. For $PM_{2.5}$ and NO_x specific emission damages from electricity generation have also been calculated, as this information may be relevant to estimate the damage costs of electrical vehicles.

In the following sub-chapters, the adaptations made in those five areas are described in more detail.

C.5.1 Changes in concentration response functions

The NEEDS project was largely based on health impact information as it was present in the WHO (2005) study on the harmful impacts of air pollution. In 2013 and 2014, the WHO presented a major update of the health impacts of air pollution. In the present study all the CRFs used in the NEEDS project were case-by-case individually checked and discussions held on whether they still reflect the latest scientific understanding. On this basis the CRFs for especially ozone pollution (> 35 ppb) and NO_x were adjusted upwards or newly impact factors have been included. In addition, a few categories of $PM_{2.5}$ pollution were revised (e.g. impact on asthmatic part of the population from $PM_{2.5}$ pollution).

In Section C.4 a detailed account of the changes in RR that have been adopted compared to the NEEDS estimate are given. In total we have updated about 7 of the 18 CRF functions in NEEDS and have introduced four new CRF functions of impacts that are reported in the WHO (2013) but have not been taken into account in the NEEDS estimates. The result is an up-to-date and precise calculation of the impacts of air pollution on human health.

The CRFs for $PM_{2.5}$ have also been applied to PM_{10} taking into account the fraction in PM_{10} that is being $PM_{2.5}$. This relationship between PM_{10} and $PM_{2.5}$ emissions is based on country-specific emissions of both pollutants as reported by Eurostat (2016 values have been taken). We have assumed that within the EU 28% of the population is living in areas with annual NO_2 concentrations larger than $20/\mu g/m^3$.

As for the CRFs of biodiversity impacts and crop losses we have not taken new information into consideration compared to the NEEDS project. As for impacts on building materials, we have followed the treatment as (CE Delft, 2018).

C.5.2 Changes in population

The size and age cohorts of the population matters for estimating the damage costs of air pollution, especially for morbidity, since some impacts (e.g. cardiovascular diseases) only affect elderly people and other impacts (e.g. asthma) only impact on younger people. Therefore, we have adjusted the age cohorts in the NEEDS study with the demographic statistics from Eurostat for the EU28.

C.5.3 Change in emission concentrations

Parts of the NEEDS model, such as the dispersion and atmospheric-chemistry models, could not be explicitly unpacked by us. However, because there are numerous NEEDS modelling runs available for estimating emission reduction scenarios, the underlying model structure can to a certain extent be derived. It was opted to proceed from the 2010 and 2020 emission scenarios in the NEEDS Excel tool (as used in the Ecosense dispersion model). Actual 2016 EU27 emissions (e.g. EU28 excluding Croatia) were then used to scale to the difference between the 2010 and 2020 values. These results were put to and discussed with atmospheric-chemistry experts and explanations for a rise or fall in damage costs per kg pollutant elaborated. In this way an adjustment was made for the lower background pollutant levels in 2015 and their influence on damage estimates. It proved that this was particularly important for the amount of ammonia in the atmosphere. NH_3, NO_x and SO_2 all react to form secondary particulates, but in the case of NO_x the relationship is linear, while for NH3 it is quadratic. Thus, as long as NH_3 do not decrease twice as fast as NO_x, an additional emission of NO_x and SO_2 will cause more damage because of the available ammonia in the air.as there will be relatively more atmospheric NH_3 for the NO_x and SO_2 to react with. This is the main reason that lower emissions of NO_x and SO_2, if unaccompanied by an equal decline in NH_3 emissions, lead to higher damage costs per kg emission for these pollutants. This impact is included in our estimates because of the basis in the NEEDS modelling results.

C.5.4 Change in valuation: human health

The change in valuation of human health impacts includes the choice of the VOLY.
That issue is covered in detail in Annex A.

C.5.5 Differentiation towards source and location of pollution

The values at the level of EU28 represent average values for average emissions in the year 2015. These have been differentiated in three different ways:

- towards average values for individual countries;
- towards emissions specifically applying for the transport sector and location of pollution (cities/rural);
- towards emissions applying for electricity generation (relevant for electrical vehicles).

This differentiation has been done by observing ratios in the NEEDS model between damage costs of EU28 compared to the national averages, and by observing ratios in the literature between the various sources of exhaust emissions. This yields insights into the likely damage costs per country for transport emissions.

We, as authors and researchers, fully acknowledge that such an approach where ratios are being used is less preferred than a new modelling effort in which the impact-pathway of emissions through the environment is being modelled for different countries and different heights of stack. However, this is very labour intensive trajectory that has only been established in very large pan-European research programs, like ExternE, CASES, Newext, CAFÉ-CBA and NEEDS. Overall over 10 million Euros of research funds have been used in these programs resulting in the EcoSense model through which MonteCarlo simulations of the trajectory of emissions have been made in order to estimate a damage cost per country and per type of emission. Such an effort is not feasible in the timeline and budget of the present project. Therefore, we have to use ratios from these bigger projects in order to estimate the likely relationship between the calculated average EU28 damage costs and the damage cost per type of emission per country. We also observe that such a 'value transfer' approach has been used more frequently in the literature (see e.g. (HEATCO, 2006); (UBA, 2012); (CE Delft, 2018). The key here is to be transparent about the modifications that have been made to the general EU figures.

Below we will elaborate on the empirical basis of our modifications.

Differentiation towards countries

Within the NEEDS project, an Excel tool was developed. From this, we have calculated the difference between the individual country estimate of damage costs and the EU27 average, as was reported in the NEEDS background documentation of the Ecosense model resulting in the Excel tool that was put online in 2008. We have used the information from the unknown height of release, damage costs in the year of release, based on average meteorology (assuming equivalent damage from secondary particles as to primary particles) corresponding to emissions from all sectors. We have found information from the EU27 average and a value per individual MS. This results in a ratio for emissions of NO_x, NH_3, NMVOC, SO_2, $PM_{2.5}$ and PM_{coarse} (e.g. PM with a diameter larger than 2.5 micrometer). For the corresponding value of PM_{10} we have assumed that this is the sum of the share of $PM_{2.5}$ in the emissions of PM_{10} of that particular country plus the damage of PM_{coarse}. For the share of $PM_{2.5}$ in PM_{10} we have used information on the national emissions of $PM_{2.5}$ and PM_{10} for the year 2015 in Eurostat.

Differentiation for transport emissions and location

For transport, we have used the information from Heatco (2006) that provides YOLL estimates for transport related impacts of emissions of $PM_{2.5}$. The relative risk of $PM_{2.5}$ emissions in Heatco is the same as applied in our study for mortality (which explains over 70% of the damage costs of $PM_{2.5}$), while the impacts on morbidity are only slightly different. We have used this information and applied the VOLY to the YOLL estimates. Heatco (2006) does not provide values for Romania, Croatia and Bulgaria. For Bulgaria and Romania we have taken the average from the YOLL values of two nearby countries: Greece and Hungary. For Croatia we have taken the YOLL as an average of Austria and Italy.

As HEATCO differentiates between the emissions from a metropole region (e.g. cities with > 0.5 million of inhabitants) and emissions outside built areas, we use this differentiation as well. In order to obtain an estimate for small and medium sized cities, we took the relationship between metropole emissions and small and medium-sized cities from a previous version from the IMPACT Handbook (Infras, CE Delft, ISI & University of Gdansk, 2008). This concludes that the impacts on small- and medium-sized cities are about 1/3 of the impact of the metropole cities.

For NO_x a differentiation between cities and rural sources of NO_x emissions has been calculated. We have taken here the assumption that 80%[54] of people living in a city is exposed to annual NO_2 values larger than 20/µg/m^3 while only 10% of people living in the countryside are not exposed to annual NO_2 concentrations larger than 20/µg/m^3 (this will be mostly people living nearby motorways). These values have then be used to calculate a specific value for emissions of NO_x located in city or rural areas for stacks up to 100 meter by adjusting the RGF (Risk Group Factor) in the NEEDS modelling result (see Annex B). Although there are indications that NO_2 emitted at ground level may be more dangerous than NO_2 emitted from higher stacks, we do not have information that would make it possible to differentiate between both sources.

Differentiation for electricity emissions

For electricity emissions we have used the ratio between the average emissions (unknown height of release) and the electricity emissions in the NEEDS project. This ratio differs per country where more densely populated countries tend to have a higher relative impact from electricity emissions than more sparsely populated countries. For Finland and Sweden, the damage from electricity generation is in general similar to the damage from lower stacks in rural areas.

C.5.6 Changes in valuation: biodiversity, crop losses and materials

To finalise and complete, the approach for the valuation (deriving cost factors) for the other non-health effects (biodiversity loss, crop loss and material damage) is also briefly described.

In CE Delft (2010), the value adopted for biodiversity was the average value of an EDP[55] per m^2 per annum of €$_{2004}$ 0.4706, based on Kuik et al. (2008). This value is the average value from a meta-analysis encompassing a number of European countries. However, the median value in this study is €$_{2004}$ 0.0604, a factor 8 lower. This implies that the overall distribution of values comprises relatively many high values (Kuik, et al., 2008). In a study on the external costs of energy production, Ecofys (2014) takes Kuik's median value rather than the average. Generally speaking, in meta-analyses more value is attached to the median than to the average.

On the other hand, an earlier study by NEEDS (2006) arrived at a PDF-value of € 0.45/€ 0.49 per PDF/m^2, the same as the average value in Kuik et al. (2008).[56] NEEDS (2006) uses the restoration-cost approach. The Éclaire project (Holland, 2014); (IIASA, 2014) investigated the economic value of air pollution impacts on ecosystem services, with biodiversity valued using WTP (as with Kuik), restoration costs and revealed preferences (costs of legislation). This project indicates that WTP-based values are conceptually the most robust, but that data availability may be a problem. In that case, use can be made of restoration costs. Restoration costs can also be used to validate WTP-values. Holland (2014); IIASA (2014) report that restoration costs represent a minimum value for biodiversity, because even after recovery genetic information may still be lost, for example. Rabl (1999) raises the

54 This is a best guess but the number can be calculated more precisely on the basis of Eurostat statistics if needed
55 Ecosystem Damage Potential, which is a slightly different measure, but (Kuik, et al., 2008) state that for all practical applications EDP and PDF can be considered identical.
56 In (CE Delft, 2010) it was reported that the average value of NEEDS (2006) was € 0.45, which is an EU-average. In NEEDS (2006) it is stated that minimum restoration costs in Germany are € 0.49/PDF/m^2. The figure of € 0.45 is a conversion from the German price level (using purchasing power parities) to an average European price level.

value of NEEDS (2006) by a factor of 2 to capture the true damage. Brink and Grinsven (2011) works with a range, multiplying the value of NEEDS (2006) by an (arbitrary) factor of 5 to obtain an upper bound and taking the value of NEEDS (2006) as a lower bound. This approach was also adopted by Grinsven et al. (2013). Holland (2014); IIASA (2014), too, state that restoration costs represent the best possible estimate.

In our study we have used the Kuik et al. (2008) estimate of the WTP since this and the restoration costs yield similar values.

Damage to agricultural crops has been added to the valuation of ecosystems. For the valuation itself the same method was employed as in NEEDS (2008), adjusting prices to present-day levels in the markets concerned. New prices have been based on average European producer prices for the EU28 as reported by FAO. Prices in USD_{2014} were converted to EUR_{2014} using the average 2014 exchange rate and then converted to $€_{2015}$ using the general Harmonized Index of Consumer Prices (HICP). These prices were then weighted by consumption of the crop concerned to determine the average price rise between 2000 and 2015. Finally, 18% VAT was added.

In Annex C.4.4 the changes in valuation of the impacts on materials and buildings are already briefly described.

D Detailed assessment climate change costs

D.1 Introduction

This annex supplements Chapter 5, presenting background information on the calculation of climate change costs. First, we discuss the effects of climate change in Section D.2. Section D.3 explores the different ways in which the costs of climate change can be assessed, delving into detail on the differences in methodology between damage costs and avoidance costs. It also describes the recommended approach in the previous Handbook, before examining new evidence on the climate change costs.

D.2 Detailed discussion on effects of climate change

When greenhouse gases are emitted into the atmosphere this leads to global warming. The (IPCC, 2013) has estimated that without concrete climate policy temperatures may be expected to rise by up to 6°C by the end of the century. Other physical effects are changes in precipitation patterns, resulting in different levels of average and extreme precipitation and changes in the occurrence of extreme weather events. Such radical change will have an important and largely irreversible impact on ecosystems, human health and societies. These impacts of climate change will not be spread equally across the globe, but rather be much worse in developing countries where there are fewer opportunities for adaptation (Global Humanitarian Forum, 2009).

The IPCC's fifth Assessment Report presents the current state of knowledge regarding the effects of climate change (IPCC, 2013). The main costs resulting from the effects of climate change are presented below:
- **Sea level rise:** An increase in temperature will result in the melting of (parts of) the polar ice caps and other snow-covered surfaces, which in turn will lead to rising sea levels. As a result, land that is currently used for living or agriculture will be lost, and more effort will need to be dedicated to the protection of coastal areas.
- **Crop failure:** An increase in temperature and changes in average and extreme precipitation can negatively affect agriculture in certain areas (whereas it may have a positive impact in other areas). These changes may manifest itself on a relatively short timescale and lead to important socioeconomic adaptation problems where famines could occur more frequently and which may trigger migration.
- **Health costs:** Temperature increases may lead to more hospital admissions and mortality as a result of heat stress. At the same time, an increase in temperature can lead to a reduction in mortality from extreme cold weather events. Changes in temperature can also lead to a larger dispersion of a number of disease that are carried by parasites or insects, such as malaria. In addition, an increase in and/or worsening of extreme weather events, such as hurricanes and heatwaves can lead to an increase in the number of fatalities from such events.
- **Damage to buildings and materials:** Climate change may lead to an increase in the frequency of extreme weather events, such as hurricanes, as well as a potential intensification of such effects. Such weather extremes can severely damage buildings, materials and infrastructure.

- **Water management issues:** Water shortages and droughts in some areas may be aggravated due to climate change, e.g. due to further salinification of ecosystems. Other areas may have more water available than anticipated based on historical levels. This will be accompanied by water management problems.
- **Impacts on ecosystems and biodiversity:** Changes in the climate may have negative effects on flora and fauna. Animals, and plants in particular, can only adapt to such changes in a limited manner. Migration and the extinction of certain species will be a likely consequence of climate change.

Each of these effects is likely to trigger human responses, which may have important socioeconomic consequences. For instance, it has been argued that one of the contributing factors to the Syrian civil war was anthropogenic climate change (Bennet, 2015; Verme et al., 2016; Adelphi et al., 2015). These effects are even harder to quantify than the direct physical costs outlined above, but are extremely important in accurately identifying climate change costs.

D.3 Assessment of climate change costs

In general, there are two major ways in which climate change costs can be calculated: using **damage costs** or **avoidance costs**. The damage cost approach values each of the individual effects of climate change and sums these together. The avoidance cost approach centres around the costs of avoiding the effects of climate change up to a desired extent (e.g. specified in a policy target).

D.3.1 Damage costs

Damage costs are an evaluation of the total costs of climate change under the assumption that no efforts are taken to reduce the pace of climate change. They are calculated using the impact pathway approach which relies on detailed modelling to assess the physical impacts of climate change. These physical impacts are then combined with estimates of their economic impacts (Watkiss, et al., 2005; Defra, 2005). Put differently, damage costs are the total present value of future costs and benefits related to the emission of CO_2.

These damage costs are calculated with the help of climate-economic models, which merge assumptions regarding climate effects with assumptions regarding future developments of (the division of) income. For instance, the damage costs of sea level rise can be expressed as the costs of land loss. Agricultural impacts can be expressed as costs or benefits to producers and consumers, and changes in water runoff might be expressed as new flood damage estimates. From a scientific point of view, it is desirable that all external effects are monetised, although this is likely to be extremely complicated as certain effects (e.g. climate feedbacks) are not yet fully understood.

Damage costs increase over time, resulting in the fact that damage costs in 2050 will be higher than damage costs in 2020. This is because of the long lifetime of carbon in the atmosphere, the decreasing discount rates used for future emissions due to uncertainties about future economic development and the non-linearity in the impacts of CO_2 emissions (Defra, 2005).

There are a number of major sources of uncertainty and weaknesses in the estimates of the damage costs of climate change (CE Delft, 2018); (Watkiss, et al., 2005); (Burke et al., 2016); (Botzen & Van den Bergh, 2012):

- *Certain important cost categories are missing in the estimates:* Economic valuation, especially in the area of climate change is often controversial. This is a consequence of the lack of knowledge about the physical impacts caused by global warming. Some effects are quite certain and have been proven by detailed modelling, whereas other possible effects, which may potentially be extremely damaging, are not yet fully understood. They are therefore either only partially or not at all included in these models. Classic examples of effects that are difficult to model are biodiversity losses, the potential effects of climate change on future economic growth, political instability, violent conflicts, prolonged flooding and behavioural change as a result of climate change, such as climate-induced migration. Furthermore, each integrated assessment model (IAM) that is used to calculate the damage costs differs in the effects that they include in the model. Examples of IAM's that are frequently used are FUND, DICE or PAGE. Therefore, the cost estimates are highly sensitive to the IAM used. These IAMS often rely on old studies and are in need of an update.

- *Uncertainty regarding the effects of climate change:* There are large uncertainties regarding the magnitude of climate change and its consequences on temperatures, sea level rise and extreme weather events. Potentially catastrophic effects, such as the melting of the polar ice caps in Greenland or West Antarctica or changes in climate subsystems such as El Niño Southern Oscillation are not, or only partly, incorporated in the analyses.

- *Uncertainty regarding the vulnerability of society*: It has been argued that IAMs underestimate the vulnerability of societies and economies to historical temperature fluctuations, and that these models are not calibrated for higher temperature variations (Revesz, et al., 2014; Marten et al., 2013). In addition, weather variability is much more important for agricultural yield (and therefore security of food supply) than average weather (Revesz, et al., 2014). This is an aspect which is not yet fully taken into account in most IAMs.

- *Uncertainties regarding the social discount rate that should be used:* As the effects of climate change occur at different points in the future, discounting should be applied. Discounting is the process of valuing future costs and benefits in terms of their value today (present value). There is a lot of discussion regarding the discount rate that should be used (see e.g. Stern vs. Nordhaus). Available damage cost estimates of climate change vary by orders of magnitude depending on the discount rate.
Defra (2005) show that damage costs can increase by a factor of 5 if a pure rate of time preference of 1% is used, as opposed to a 0% rate. The different discount rates that can be used reflect theoretical valuation problems related to equity, irreversibility and uncertainty. For equity both intergenerational and intra-generational equity should be considered.

- *Risk aversion and loss aversion are not taken into account properly:* In general people are risk averse and loss averse. Risk aversion implies that when exposed to a situation with an unknown payoff, there is a preference for a more predictable lower expected payoff. Loss aversion implies that individuals do not value gains and losses in the same manner. Translating this to the climate implies that humans should prefer a more costly route that leads to lower warming with more certainty than a less costly route where there is more uncertainty about the extent of the warming. Similarly, as humans are loss averse they will need to be overcompensated for losses in the climate as we know it. Most studies do not take these psychological aspects into account at all in their climate change cost calculations (or if they do then only to a very limited extent).

— *Equity weighting:* Although climate change is a global problem, it will give rise to different impacts in different countries, which each have different levels of development. To account for these income differences equity weighting may be applied. As the marginal utility of consumption is declining with additional consumption, a richer person will obtain less utility from extra money available than a poorer person. Equity weighting implies that climate change impacts are weighted differently based on which region of the world the impacts take place, taking into account differences in the marginal utility of consumption. Studies have shown that the use of equity weights could increase damage costs by a factor of 10 (Defra, 2005; Anthoff & Tol, 2007).
In general there are two approaches to equity weighting (Friedrich, 2008):
  - World average weights: Using world average weights entails adjusting regional monetary values to a world average income. The value of climate damages in Europe would be lowered, whereas the value of climate damages outside of Europe will increase. As most of the climate change damages will occur outside of Europe, this equity weighting approach will result in higher damage costs than damage costs that do not use equity weighting.
  - Regional/EU weights: Using regional/EU weights implies that the damages are valued by the monetary value from the region in which GHG are emitted. This would imply that European values should be applied to all damages caused by European GHG emissions. This approach can be justified from an ethical point of view as Europe would pay for (the risks of) the damages they are causing, and would result in higher damage costs than an approach where equity weighting is not considered.

— *The assessment of the baseline scenario:* The state of the baseline scenario with global long-term economic development, technological development and the associated greenhouse gas emissions, is important to determine the marginal external costs of additional CO_2 emissions. Some IAMs do not take into account the effect that climate change has on labour productivity and general productivity. These, in turn, affect economic growth, and lead to an intensification of the welfare loss through the interest rate effect. Therefore, uncertainty regarding the baseline scenario is a source of uncertainty in the estimates of climate change damage costs.

— *Adaptation measures:* Adaptation measures have the potential to lower damage costs, however, they are currently barely taken into account in the calculation of damage costs.

D.3.2 Avoidance costs

Avoidance costs centre around the marginal costs of achieving a certain level of environmental quality (usually determined by policy). The method is based on a cost-effectiveness analysis, which determines the least-cost option to achieve a required level of GHG emission reduction. This approach has been applied and recommended in several studies (UNITE & ExternE).

Crucial to the use of avoidance costs is the level of the emissions target that is set.
To achieve accurate avoidance costs, this level has to reflect society's target level of CO_2 reductions. Several targets are relevant at the EU level:

— A reduction of CO_2 emissions of 20% by 2020 compared to 1990 levels. This is the EU target that has been detailed with concrete measures (e.g. the EU ETS, Effort Sharing Decision, etc.).

- The policy target that the EU has agreed upon for 2030 (at least 40% reduction by 2030 compared to 1990 levels).Concrete measures have also recently been agreed for 2030 (e.g. revision of the EU ETS, Effort Sharing Regulation, etc.)
- The target mentioned in the Paris Agreement (below 1.5 or 2 degrees warming), which implies a target of 80-95% reduction in CO_2 emissions by 2050 compared to 1990 levels.

From a welfare economics perspective the avoidance cost approach is not a first-best solution (Defra, 2005) as it does not directly measure and value all impacts of climate change. However, if the emissions target adequately reflects the preferences of society and can therefore be used to determine society's WTP for a certain abatement level, the avoidance cost approach can be seen as a theoretically sound alternative. Ideally, to indicate the social desirability of the target, the targets should be confirmed by binding policies.

As humans are known to be risk averse, risk aversion should be taken into account in the assessment of climate change costs. The precautionary principle[57] was introduced in climate policy to take this risk aversion into account. After all, there are certain risks of climate change that could create very high damages in the long run (e.g. methane outbursts, loss or reversal of the Gulf Stream). However, there are currently no methodologies that include marginal risk aversion in the assessment of damage costs. Therefore, the only way to include risk aversion and the precautionary principle in the assessment is through using an avoidance based approach, assuming that the political decision of the reduction target does take these unknown, but important impacts into account.

There are a number of important aspects in determining the avoidance cost estimates:
- *The choice of target level:* Avoidance cost estimates are highly sensitive to the choice of target level. A stronger emission reduction target will imply higher costs than a lower emission reduction target. However, the target level is also sensitive to the system to which the target is applied. For instance, whether the target holds for all sectors or specific sectors (e.g. transport-only) will affect the cost estimate. Similarly, costs may differ depending on whether the target set is valid at the national level or the supranational level. If the emissions target chosen does not reflect the preferences of society, this methodology will not be optimal from a welfare economics perspective.

- *Estimation of options for mitigation:* Avoidance costs rely on the accurate prediction of technological progress and technological breakthroughs. Such progress or efficiency gains can reduce the costs of the technologies used in the baseline scenario, as well as those of the additional measures. A factor that is of particular interest here is the future development of the energy prices. With low energy prices, abatement options will be very expensive, whereas with higher energy prices abatement options will be cheaper.

- *Estimation of baseline scenario:* Avoidance costs are highly reliant on assumptions regarding the development of GHG emissions. These mainly depend on the development of the world economy and fuel prices, which are in turn influenced by policies (to be) taken. Higher baseline GHG emissions imply more abatement policies need to be taken, resulting in higher avoidance costs. Similarly, lower baseline GHG emissions, for example due to lower global economic growth, will result in lower avoidance costs.

[57] Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation – Rio Declaration on Environment and Development.

- *Different GHGs:* Some measures that prevent emissions are GHG specific, therefore, their costs are also GHG specific. Thus, the costs of avoiding CH_4 or N_2O emissions cannot always be deduced from the behaviour of those GHG in the atmosphere compared to CO_2, for instance by comparing the GWP of the different gases.
  For instance, the costs of reducing a tonne of CH_4 may not be proportional to the costs of reducing 34 tonnes of CO_2.[58] Avoidance costs are usually expressed per tonne of CO_2 equivalent, rather than calculating separate avoidance costs for each gas. Numerous studies have shown that CO_2-specific avoidance costs are lower than the avoidance costs for CH_4 and N_2O (Jakeman & Fisher, 2006; Kemfert et al., 2006; Kurosawa, 2006; Tol, 2006; Gambhir et al., 2015).

- *Risk and loss aversion:* This is an import issue for both avoidance and damage costs. For avoidance costs it can only be taken into account when one assumes the political decision underlying the reduction target takes risk and loss aversion into account.
  For more detail please see Section D.3.1.

- *Equity weighting:* This is an important issue for both avoidance and damage costs, for more detail please see Section D.3.1.

EU ETS
In principle, an emissions cap-and-trade scheme, such as the EU Emission Trading Scheme, can be seen as a variant of the avoidance cost approach. However, emission trading prices only reflect social costs when the allocated maximum emissions equal the optimal level from a welfare economics point of view (Smith & Braathen, 2015). In the EU ETS there is a surplus of allowances (EC, 2016), such that the socially optimal emissions level cannot be reached. This will change in the future because of the Market Stability Reserve. Furthermore, the use of the current emissions trading prices as a proxy for avoidance costs is limited to the CO_2 emissions only in the markets that are included in the EU ETS (Smith & Braathen, 2015). As there are sectors that are not included in the EU ETS, the use of EU ETS trading prices is not likely to be representative for CO_2 emissions in sectors outside the EU ETS or for other pollutants (CH_4 or N_2O). Because of these reasons, this variant of avoidance costs will not be explored further here.

D.3.3 Recommended approach previous Handbook

In the first edition of the Handbook (Infras, CE Delft, ISI & University of Gdansk, 2008) the use of **avoidance costs** was advised for the short term (up to 2020). For the long term (2030-2050) the use of **damage costs** was recommended, as no global long term climate goals had yet been established.

In the second edition of the Handbook (Ricardo-AEA, TRT, DIW Econ & CAU, 2014) the use of **avoidance costs** was exclusively advocated. The target level of emissions was 450 ppm CO_2 equivalents, which corresponds to 2˚C of warming. A climate change costs per tonne of carbon of € 90 was used.

[58] The GWP of CH_4 is 34, observing over a 100 year period.

D.3.4 New evidence climate change costs

Damage costs - Values

Since the early literature on damage costs carried out in NEEDS (Anthoff, 2007) or the Stern Review (Stern, 2006) there have been numerous studies that have examined the damage cost approach (Tol, 2008; Botzen & Van den Bergh, 2012; Van den Bijgaart, et al., 2013; Waldhoff, et al., 2014; Ackerman & , 2012; IAWG, 2013; Moore & Diaz, 2015; Gillingham, et al., 2015; Tol, 2013).

A meta-analysis conducted by Tol incorporating 211 studies revealed that there is an enormous spread in the results of damage costs (Tol, 2008). Values range from less than € 1/tCO_2 to more than € 500/tCO_2, with an average damage cost of € 5/tCO_2[59] (Tol, 2008). However, he notes that the chances of the average damage cost exceeding € 20/tCO_2 are less than 1%. Therefore, Tol argues, the damage costs presented in the influential Stern Review ($85/t$CO_2$) (Stern, 2006) are an outlier. Many researchers have argued that Tol's claims are premature as damage costs are characterised by very high uncertainty (Botzen & Van den Bergh, 2012; Van den Bijgaart, et al., 2013). (Van den Bijgaart, et al., 2013) have attempted to take away most of that uncertainty, by modelling damage costs using only the most crucial parameters and Monte Carlo methods. They conclude that average damage costs amount to € 37/tCO_2, median damage costs are € 17/tCO_2 and the chances of damage costs exceeding € 100/tCO_2 are 8% (Van den Bijgaart, et al., 2013), all of which are significantly higher than Tol's estimates.

In general, recent studies find higher damage costs than the early study conducted by (Anthoff, 2007). Recent literature that use the same IAM (FUND) results in values that are 1.3-3.4 times higher than those provided by (Anthoff, 2007) (e.g. (Anthoff, et al., 2011; Waldhoff, et al., 2014)). Studies that don't (only) rely on FUND find values that are between 1.8-6.9 and 2.7-17 times higher for current (< 2025) and future (± 2050) emissions respectively (Ackerman & Stanton, 2012; IAWG, 2013).[60] Only one recent study found a lower damage cost value than Anthoff (2007), although the costs were not calculated using one IAM, but rather as an average of the results of three IAMs (Gillingham, et al., 2015).

Anthoff's (2007b) damage costs for emissions in the near future are negative when using high discount rates (>1%), which is likely to be as a result of the CO_2-fertilisation effect. However, similar recent studies (Moore & Diaz, 2015; IAWG, 2013) dispute this.
Their findings suggest these costs are positive. Lastly, when comparing Anthoff (2007)'s values to the meta-analysis carried out by (Tol, 2013) minor differences (factor 1.7) are observed for mean damage costs, but strong differences (factor 17) are observed for median costs.

Avoidance costs - Values

The first edition of the Handbook used avoidance costs to calculate climate change costs for just the short-term (Infras, CE Delft, ISI & University of Gdansk, 2008). However, since then multiple studies on the external costs of transport have switched to using avoidance costs for both the short-term and the long-term costs (Ricardo-AEA, TRT, DIW Econ & CAU, 2014; CE Delft, INFRAS & Fraunhofer ISI, 2011) (CE Delft, 2018). These three studies all base their

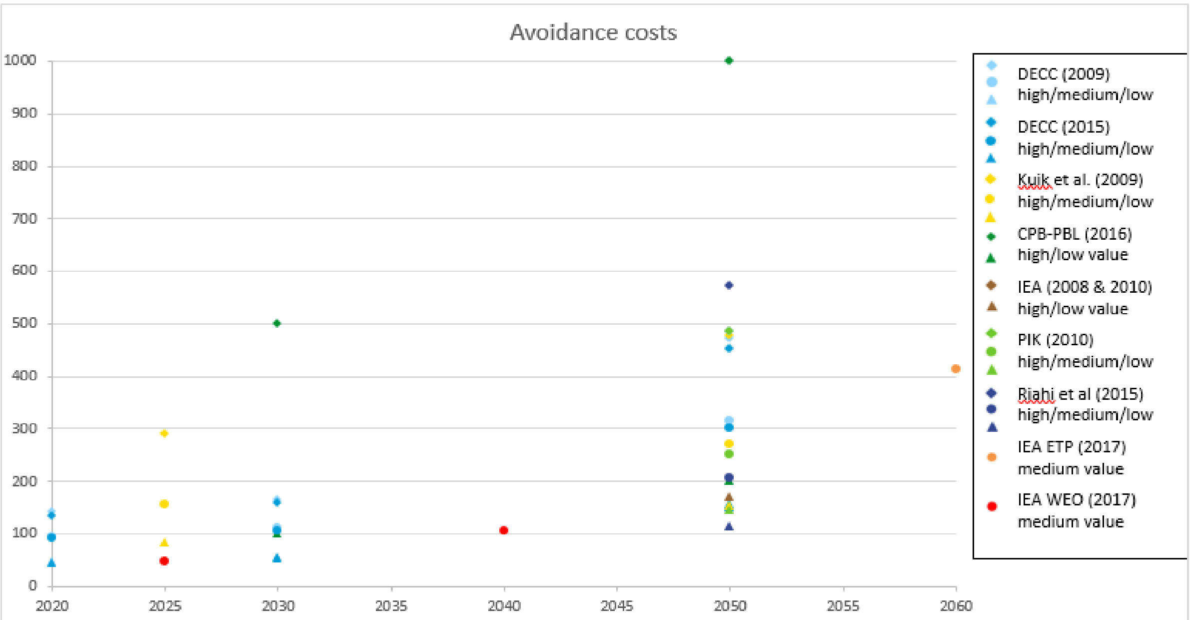
[59] For CO_2 that is currently being emitted, using a 3% discount rate.

[60] Using a low pure rate of time preference (between 0 and 1%).

avoidance costs on the same paper by (Kuik, et al., 2009), which is the most recent meta-analysis study of avoidance costs. It consists of 26 studies with 31 avoidance costs estimates. However, most of the studies included in their analysis present avoidance costs for relatively high ppm targets. For instance, 19 of the 31 avoidance costs estimates included in their analysis investigated a target of 650 ppm or higher. Only one study included looked at a target of 450 ppm. Kuik et al. therefore extrapolates based on the cost estimates for higher ppm targets, to ultimately present avoidance costs for 450 ppm. Arguably, the Kuik et al.'s (2009) extrapolated avoidance cost estimate for 450 ppm is 'out of sample'. However, if we look at Kuik et al.'s values only seem to somewhat stand out for 2025. For 2050 the cost estimates appear to be in line with the rest of the literature.

The main new studies that have been published since previous editions of the Handbook are (DECC, 2009), (DECC, 2015), (CPB; PBL, 2016), (IEA, 2008) & (IEA, 2010), (IEA, 2017b) & (IEA, 2017a) (Riahi, et al., 2015) and a range of studies conducted by researchers at the Potsdam Institut für Klimafolgenforschung ((Edenhofer, et al., 2010), (Kitous, et al., 2010), (Magné, et al., 2010), (Leimbach, et al., 2010), (Barker & Scrieciu, 2010) and (D.P., et al., 2010)). The figure shows the low (triangle), central (round) and high (diamond) value from the various studies. In general, the values for 2025 from Kuik et al lie slightly higher than the rest of the literature values, whereas the CPB-PBL (2016) values for both 2030 and 2050 are extremely high compared to the rest of the literature.

Figure 18 – Review of avoidance cost values found in the literature (€$_{2016}$/t CO_2 equivalent)



The avoidance costs used in this Handbook are based on an average of the values found in the literature, grouped according to the short-and-medium-term (up to 2030) and the long term (2040-2060). The values for both these time periods were reached by calculating the average of all central estimates, excluding the lowest and the highest one to eliminate outliers. This provides us with a central avoidance cost value of € 100 in short-and-medium-term. This process was repeated for the low and high estimates, which are € 60 and € 189 in the short-and-medium-term respectively. Table 82 also shows the avoidance costs for the long term. In the long term the climate costs were shown to have a central estimate of € 269/tCO_2 equivalent.

Table 82 - Climate avoidance costs in €/tCO_2 eq. (€$_{2016}$)

	Low	Central	High
Short and medium run	€ 60	€ 100	€ 189
Long run	€ 156	€ 269	€ 498

It is important to note that excluding 2030 from the cut-off point between the short-and-medium-run vs. the long run would not significantly change the short-and-medium-run avoidance cost estimates. This cut-off is currently set at 2030, but if one were to set it at 2025, the low, central and high estimates for the short-and-medium, run would change to € 59, € 97 and remain at € 189 respectively, all very minor changes.

D.3.5 Conclusions

Despite significant advancements in the field of damage cost calculation we use **avoidance costs** to calculate climate change costs. This brings us in line with the previous edition of the Handbook. Numerous studies have advocated the use of avoidance costs rather than damage costs (CE Delft, INFRAS & Fraunhofer ISI, 2011; DECC, 2009; DECC, 2015; Isacs et al., 2016; Smith & Braathen, 2015) (CE Delft, 2018). The major weakness of the damage cost approach is the fact that all climate damages need to be fully understood and quantified. Although many of the climate damages are somewhat understood, there are certain feedbacks and potentially extreme events that are not yet fully understood. Furthermore, the spread of results from different studies assessing climate costs based on avoidance costs is significantly smaller than for studies using damage costs. This seems to suggest that there is more certainty around the avoidance costs estimates than the damage costs estimates.

The biggest argument for the use of avoidance costs rather than damage costs is the fact that countries have signed up to the Paris Agreement. Since the EU ratified the Paris Agreement on the 5th of October 2016, committing itself to limit the increase in global average temperatures to well below 2 degrees above pre-industrial levels (this can be roughly translated to 450 ppm CO_2 equivalents), we have reason to believe this is a credible long-term reduction target, which is representative of the interests of society, and which we can use as a target to base the avoidance cost on. Furthermore, if the Paris Agreement is to be retained, then the marginal cost of extra CO_2 from transport will need to be offset by reduced emissions elsewhere. This implies that it is not extra damage from global warming, but extra avoidance in other sectors. Therefore, there will be no additional damage costs, only avoidance costs of CO_2.

The avoidance costs used in this Handbook are based on the analysis presented in Section D.3.4. Therefore, the costs are not based on a single study, but rather on multiple studies, resulting in a central climate changes cost estimate of € 100 per tonne CO_2 equivalent for the short-and-medium-term.

E Detailed assessment of noise costs

E.1 Introduction

This annex presents more information on how noise costs are calculated, supplementing Chapter 6. First we discuss the effects of noise on health and annoyance in more detail in Section E.2. Section E.4 elaborates how noise from different sources is experienced in different manners. Lastly, Section E.5 explores the total and average noise costs in more detail, describing the approach in the previous Handbook, examining new evidence and providing updated values for annoyance and health costs.

E.2 Detailed discussion on effects of noise

Two major impacts are usually considered when assessing noise: **annoyance** and **health endpoints**. Some studies consider annoyance effects as health related effects (Defra, 2014) (IGCB, 2010). These studies follow recommendations from (WHO, 2011) where physical, mental and social well-being are considered part of health. Other studies explicitly differentiate between annoyance and health related effects of noise (Bristow, et al., 2015) (Nelson, 2008). In this study, we take into account both the costs of annoyance and the costs of health separately, although they are closely linked. Although noise may also result in direct material damages as a result of noise vibrations, such damages are not included in the noise costs mentioned in this paper, because of a lack of data. This is in line with the scope of the previous versions of this Handbook.

Annoyance represents the disturbance individuals experience when they are exposed to traffic noise. It can hinder people in performing certain activities, which may lead to a variety of negative responses, including irritation, disappointment, anxiety and exhaustion (WHO, 2011). In addition, general wellbeing may be affected. This may be particularly prevalent during a sunny day spent outside.

Health endpoints can take a multitude of forms. Recently, the WHO commissioned a series of systematic reviews for the health effects of environmental noise (R., et al., 2017) (M.J., et al., 2017) (Kempen, et al., 2018) (Clark & Paunovic, 2018) (Sliwinska-Kowalska & Zaborowski, 2017) (Basner & McGuire, 2018) (Brown & van Kamp, 2017). Their aim was to conduct extensive meta-analyses in order to classify the evidence base for the health effects according to four definitions:

High quality:	Further research is very unlikely to change our confidence in the estimate of the effects.
Moderate quality:	Further research is likely to have an important impact on our confidence in the estimate of the effect and may change the estimate.
Low quality:	Further research is very likely to have an important impact on our confidence in the estimate of the effect and is likely to change the estimate.
Very low quality:	Any estimate of the effect is uncertain.

Looking purely at the health endpoints for which the WHO classifies evidence as 'high quality' implies that only ischaemic heart disease as a result of road noise should be taken into account. If we also take into account those health endpoints for which evidence is classified as 'moderate quality' the list significantly expands (see Table 83).

Table 83 - Health endpoints of noise for which the evidence is classified as at least 'moderate quality' by the WHO

Road	Rail	Aviation
Ischaemic heart disease	Diabetes	Stroke
Stroke	Certain reduced cognitive abilities	Certain reduced cognitive abilities
Diabetes	Sleep disturbance	Obesity
Sleep disturbance		Sleep disturbance

A brief summary of a few of the main health endpoints of traffic noise included in the 2018 WHO Systematic Reviews are presented below:

- *Cardiovascular diseases and hypertension*: Multiple studies have confirmed the link between cardiovascular disease and traffic noise (Seidler, et al., 2015) (Ecoplan & Infras, 2014) (WHO, 2011). Furthermore, there is increasing evidence that traffic noise increases the risk of hypertension (Health & Safety Laboratory, 2011), which not only contributes to increased risk of cardiovascular disease, but also increases the risk of *stroke* and *dementia* (Defra, 2014).
- *Sleep disturbance*: Sleep disturbance as a result of traffic noise raises stress levels, reduces wellbeing due to insomnia and tiredness, increases irritability and reduces social contacts (Fraunhofer ISI & Infras, 2018). Furthermore, evidence suggests a link between *diabetes* and exposure to traffic noise through sleep disturbance (Sørensen, et al., 2013) (Babisch, 2014). Changes in sleeping patterns have been linked to changes in eating habits, which have been associated with an increased risk of type 2 diabetes and obesity.
- *Cognitive impairment*: Chronic and acute exposure to aircraft noise seems to affect the long-term memory and reading capabilities of children (Guski & Schreckenberg, 2015). Similar effects have also been identified for road noise (Dreger, et al., 2015).

In addition, studies have reported a number of other health endpoints that are not supported by the latest WHO Systematic Reviews:

- *Breast cancer*: Three cohort studies have shown significant correlations between breast cancer in women and traffic noise, but only for specific ranges of noise nuisance and types of breast cancer (Seidler, et al., 2015) (Greiser & Greiser, 2015) (Sørensen, et al., 2014). For standardised noise measures and all types of breast cancers, no significant correlation was found.
- *Depression*: There are currently very few recent studies exploring the link between depression and traffic noise. Clearly significant findings from (Seidler, et al., 2015) suggest a strong correlation between the prevalence of unipolar depression and exposure to traffic noise. (Greiser & Greiser, 2009) find similar significant findings, but only for women.
- *Tinnitus*: Tinnitus, the hearing of sound when no external sound is present, was included in the health effects of noise by the WHO in 2011, but not in the most recent WHO Systematic Review. Tinnitus is usually caused by chronic exposure to noise levels above 85 dB(A), a noise level not usually reached by traffic noise. Therefore, we propose not to include these aural noise effects in calculating the costs of noise.

Overall, there appears to be weaker evidence for these latter three health endpoints of traffic noise. In addition, they are not supported by the WHO in their latest Systematic Reviews. For this purpose, we will not include the costs of breast cancer in women, depression or tinnitus in the costs of noise. Nonetheless, it is important to note that the WHO evaluated the quality of the evidence according to very strict guidelines valid for clinical medicine.

In this study, we take into account both the costs of annoyance and the costs of health separately, although they are closely linked. For instance, sleep disturbance is classified as a health impact according to (Defra, 2014) although there is likely to be significant overlap with annoyance. These two impacts are difficult to separate. In WTP studies looking at noise it is complicated to separate individual's valuation for annoyance from sleep disturbance. If one is asked about their annoyance they are inclined to also take into account the effects of sleep disturbance. Therefore, there is an implicit risk of double counting valuation if both sleep disturbance and annoyance impacts are explicitly taken into account. To avoid double counting we employ the conservative assumption that sleep disturbance is excluded from the health endpoints and is only considered in the annoyance endpoint. The health endpoints that we do include in this study are ischaemic heart disease, stroke and dementia (the latter two both indirectly through hypertension).

In addition to the costs of annoyance and costs of health, there are a number of **other effects** as a result of exposure to noise, including disturbance of quiet areas, effects on ecosystems and effects of restricted land use. Due to the novel nature of research and complexity of their valuation, none of these effects are incorporated in this study.
- *Disturbance of quiet areas*: There is evidence of a peaceful environment, or 'quiet areas', being negatively impacted by noise (Anastasopoulos et al., 2011). Noise reduces the quality of the quiet areas, such as parks, experienced by recreational users. As these areas are classic public goods without a market price, valuing them is difficult. Lack of appropriate valuation of these quiet areas prevents the negative effects due to noise from being incorporated in this study.
- *Effects on ecosystems*: A growing number of studies have indicated that (man-made) noise influences the wellbeing of animals. Noise may result in behavioural change in animals, leading to reduced reproductive success and species density (Dutilleux, 2012). Due to the novel nature of research in this area, it is not yet possible to quantify these effects (Dutilleux, 2012).
- *Cordon sanitaires*: An additional impact of transport noise is the restricted land use possibilities in areas around airports and some (rail) roads. In many countries governments establish 'cordon sanitaires' around large noise sources like airports. In these cordon sanitaires land use is restricted, and building new houses is prohibited. These restrictions in land use change, result in welfare losses and hence should be taken into account by estimating the external costs of noise. However, due to lack of available data on this issue, we will not estimate these costs in this study.

Lastly, individual and collective behavioural responses to noise exposure, such as avoidance measures (e.g. the closing of windows, choice of residential area, good noise isolation and moving house) or adaptation, are not included in the valuation of noise in this study. The reasons for this are twofold. Firstly, these behavioural responses can be extremely difficult to measure, and secondly, because their importance is deemed an order of magnitude less important than the costs of health and annoyance (Fraunhofer ISI & Infras, 2018).

For a list of the impacts of noise that are included in the valuation in this Handbook we refer to Section 6.2 and Section E.5.3.

E.3 Noise data

The data used to calculate the noise costs from transport is based on data from the EEA. The number of people exposed to road and rail noise is based on data provided by Member States under the frame of the Environmental Noise Directive that are compiled by EEA (EEA, 2018). The data for road and rail are divided into:

- noise in agglomerations: It concerns agglomeration defined in the Environmental Noise Directive (END) scope (> 100,000 inhabitants);
- noise on majors roads (> 3 million vehicles/year) and majors railways (> 30,000 train passages per year).

The compiled data, however, are not complete as not all data have been reported and not all cities and urban regions are included in the scope of the noise directive. The following corrections have been applied to complete unreported data on agglomerations to be reported:

- For countries with partly incomplete reporting of agglomerations, the number of people exposed to the different noise-bands have been estimated by extrapolating the reported number to the to-be reported number, linearly with the number of inhabitants (reported and to-be reported).
- For countries that have no data at all (Greece) the relative exposures per noise band of a neighbouring country (Bulgaria) have been applied on the number of people to be reported.

For major roads and railways the following corrections have been applied:

- For countries with partly unreported kilometres road or railway, the number of people exposed to the different noise-bands have been extrapolated from the reported kilometres road or rail to the to-be reported kilometres road or rail (linearly with the kilometres road or railway).
- For countries that have no data at all (Greece, Estonia) the exposed people per kilometre road or rail of a neighbouring country (Bulgaria, Lithuania) have been applied on the kilometres road or rail to be reported.

To also include people exposed to road and rail noise in areas that are not within the scope of the Environmental Noise Directive the following procedure has been applied:

- Data from Eurostat (Eurostat, 2018) on the number of people living in cities (areas with a centre with a density > 1,500 inhabitants/km^2) and people living in towns and suburbs (> 300 inhabitants/km^2) were extracted.
- The number of people in cities has been compared with the number or people in the agglomeration to be reported. For countries where the number of people in cities is higher than in agglomerations, the same level of exposure is assumed for the unreported people in cities as for people in the reported agglomerations.
- The number of people in towns and suburbs has been compared with the number of people in agglomerations minus the people in cities. For countries where the number of people in towns and suburbs is higher, it was assumed that unreported people in towns and suburbs were exposed to 3 dB lower noise levels than people in the reported agglomerations. This was done to account for the differences in noise exposure between cities and suburbs.
- (A part of) the population exposed in unreported cities, towns and suburbs may already be covered by the reporting under major roads and railways. To correct for this, it has been assumed that the same coverage of unreported cities, towns and suburbs for major roads applies to reported agglomerations under major roads. So if the exposed people to major roads in agglomeration is 40% of the exposed people in agglomerations, it is assumed that 40% of the estimated unreported exposures is also covered by the

reporting under major roads. This means the estimated exposure in unreported cities, towns and suburbs is corrected by subtracting the exposed people with 40% of the exposed people. The number of subtracted people, however, cannot be higher than the number of exposed people under major roads.

E.4 Noise nuisance compared between modes

Noise originating from different sources, but at the same volume, is not experienced in the same manner. This was shown by Table 82, where evidence for the *health* endpoints of noise is not homogenous across transport modes. In addition, different levels of *annoyance* result from rail, road and aviation noise at the same volume. In previous editions of this Handbook, the concept of the rail bonus was upheld to account for the lower level of annoyance for rail noise in comparison to road noise. The rail bonus gives rail transport a 5 dB 'discount' in comparison to road noise, implying rail noise at 55 dB is considered equally annoying as road noise at 60 dB.

However, some recent studies have indicated that relationships between noise level and reported annoyance are stronger for railway noise than for road noise (Guski et al., 2017), or that this relationship holds below or above certain noise levels (Bodin et al., 2015) (Lercher, et al., 2010). Furthermore, some studies found night-time railway noise to be more annoying than road noise (Elmenhorst et al., 2012) (Elmenhorst et al. , 2014). Other studies, using physical indicators for annoyance such as heart rate, systolic blood pressure and stress biomarkers, have not shown a different response to rail noise, compared to road noise (Gallash et al., 2016). As the literature is not unanimous, evidence makes it hard to continue to support the rail bonus. Contradicting evidence from hedonic pricing studies (see Section E.5.2) also complicates upholding the rail bonus. Therefore, based on the aforementioned literature, we have decided to no longer include a rail bonus in the costs of annoyance from noise in this Handbook.

E.5 Assessment of total and average noise costs

E.5.1 Recommended approach previous Handbook

Annoyance costs

Earlier editions of the Handbook valued annoyance based on the SP results of HEATCO (Navrud, et al., 2005). HEATCO's values are based on a general shadow price of noise nuisance of € 25 per dB per household, which was then translated to the different national circumstances. The 2014 edition of the Handbook also used HEATCO's values, and merely corrected them for inflation.

Health costs

For health costs, earlier editions of the Handbook were based on UNITE (2003). The health endpoints covered were: hypertension, angina pectoris and myocardial infarction. To evaluate the economic costs of these health endpoints a VOLY of € 40,300 (price level 2002) was used. The cost of illness approach was applied to estimate the medical costs.

E.5.2 New evidence annoyance costs

Stated Preference (SP)

Since HEATCO, there has only been one extensive meta-analysis of SP studies in this area, carried out by (Bristow, et al., 2015). Their study is the first meta-analysis and most extensive review to date of SP studies of transportation noise nuisance. Their meta-analysis is based on a compiled data set of 258 values from 49 studies and 23 countries, and spans a period of more than 40 years. In contrast, the most extensive meta-analysis of hedonic pricing includes 53 noise valuations. A novel aspect in their study is the presentation of higher monetary valuations for higher levels of noise, something which was previously hinted at by (Kruitwagen, et al., 2006). Moving from 55 to 56 dB is no longer valued the same as the move from 75 to 76 dB. This is in stark contrast with HEATCO, which used a constant valuation per dB. The increased valuation with increased noise levels is in line with the valuation used in several European countries (e.g. Denmark, Sweden and the UK). Bristow et al.'s (2015) study provides annoyance values for road and aviation noise, but not for rail noise.

Table 84 illustrates the values from (Bristow, et al., 2015)'s study adapted to the average income for the EU28, expressed as the WTP for a welfare loss (increase in noise level) per person per dB.

Table 84 – Valuation of noise annoyance in the EU28 in €$_{2016}$ per person per dB, L_{den}

	50-55 dB	55-64 dB	> 65 dB
Road	14	28	54
Aviation	34	68	129

Revealed Preference (RP)

There have been a few studies investigating noise annoyance through RP since the last Handbook was published. Table 84 presents an overview of the Noise Sensitivity Depreciation Indexes (NSDI) from a vast amount of literature, both old and new, and shows that newer studies don't find vastly different results. The NSDI ranges from 0.08 to 2.22. However (Bateman et al., 2002) and (Navrud, 2002) both suggest that the average NSDI is probably found at the bottom of that range (0.55). More recent studies agree with them. Assuming an average price of € 230,000, an average household size of 2.2 people, a discount rate of 5% and a duration of 10 years, the NSDI of 0.55 corresponds to a WTP of € 75 per person per dB per year. This value matches well with the values that (Bristow, et al., 2015) provide for higher noise levels.

Whether or not the valuation of noise increases more steeply with higher levels of noise has also been investigated by the hedonic price literature. Both (Theebe, 2004) and (Udo, et al., 2006) have explicitly taken a non-linear relationship into consideration. (Theebe, 2004) find this effect holds for noise levels above 65 dB, whereas (Udo, et al., 2006) witness this effect for the entire range of noise levels.

Table 85 – Noise Sensitivity Depreciation Index (NSDI) results of hedonic price studies

Study	NSDI Road	NDSI Rail	NSDI Aviation
(Bateman, et al., 2001)	0.20		0.25
(Bateman et al., 2002)	0.55 (0.08-2.22)		
(Navrud, 2002)	0.08-2.22		
(Theebe, 2004)	0.0-0.5	0.0-0.5	0.0-0.5
(Popp, 2006)	0.48	0.48	0.48
(Udo, et al., 2006)	1.7 (1.1-1.9)	1.7 (1.1-1.9)	
(Day, et al., 2007)	0.18-0.55	0.67	
(Nellthorp, et al., 2007)	0.2-1.07	0.67	
(Dekkers & van der Straaten, 2008)	0.16		0.77
(Nelson, 2008)	0.4-0.6		0.7-0.9
(Duarte & Tamez, 2009)		0.08	0.08
(Andersson et al., 2010)	1.35-2.9	0.08-4.09	
(Lijesen, et al., 2010)			0.8
(Brandt & Maennig, 2011)	0.23	0.11	0.13
(Getzner & Zak, 2012)			0.85 (0.5-1.3)
(Andersson et al., 2013)	1.15-2.9	0.08-4.09	
(Ecoplan & Infras, 2014)	0.21	0.24	
(Andersson, et al., 2015)	0.3	1.3	
(Swoboda, et al., 2015)	0.5		
(Beimer & Maennig, 2017)	0.61	0.65	1.27
(Winke, 2017)			1.7

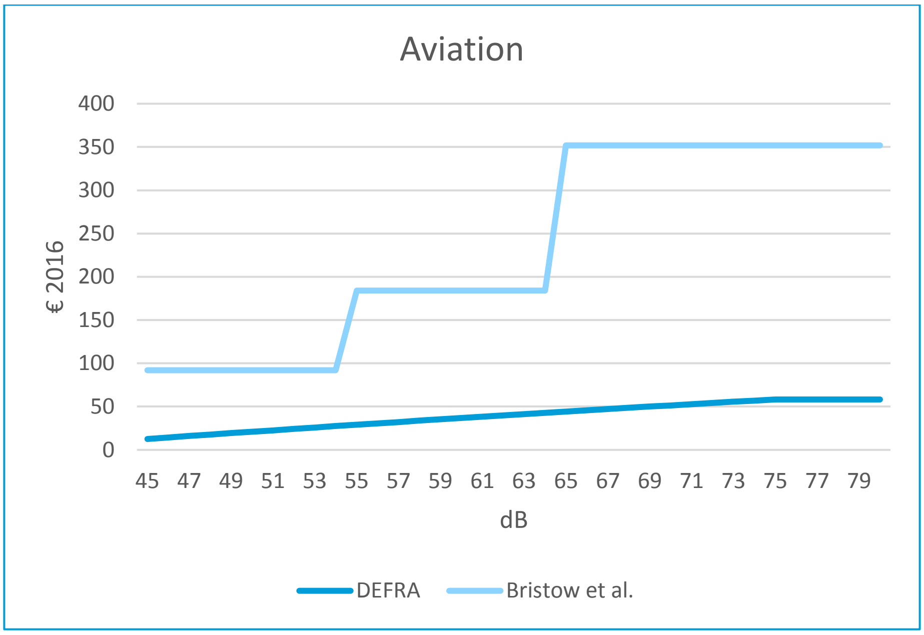
Furthermore, the studies presented in Table 85 support the acoustic literature (e.g. (Miedema & Oudshoorn, 2001) which suggests that people consider noise from aircraft more of a nuisance than road noise. However, the results are not harmonised in terms of justifying the rail bonus (see Section E.4). The results from (Andersson et al., 2010) and (Andersson et al., 2013) suggest road noise is more of a nuisance than rail noise, which is in line with the acoustic literature, and supports the existence of a rail bonus. However, the studies by (Day, et al., 2007) and (Dekkers & van der Straaten, 2008) find higher NSDI values for noise originating from rail than road noise. These conflicting results are one of the reasons for not incorporating the rail bonus in this edition of the Handbook (see Section E.4).

Environmental burden of disease (EBD)

Although the EBD method seems more appropriate to value health effects, it has also been used to value annoyance, e.g. by (Defra, 2014). (Defra, 2014) uses dose-response functions to identify the proportion of people that are highly annoyed at a certain noise level. This number is then multiplied with the (WHO, 2011) disability weights (see Annex A.2), where noise annoyance has a central value of 0.02 (ranging from 0.01–0.12). The resulting number is then multiplied by the health value in the UK. This was set at £ 60,000 per Disability-Adjusted Life Year (DALY).

Comparing (Defra, 2014) to the SP results from (Bristow, et al., 2015), shows that the EBD method results in considerably lower valuation than the SP method (see Figure 19). This can (partially) be explained through the fact that the EBD method uses a conservative approach for multiple reasons. Firstly, it only incorporates nuisance by highly annoyed persons (%HA). Annoyed people (%A) are not taken into account using this valuation methodology. It is currently not possible to correct for leaving out the less severe forms of annoyance, as (WHO, 2011) does not provide any disability weights that could be used to make these adjustments. Secondly, the WHO recommended disability weights of annoyance of 0.02 (range spanning 0.01-0.12) is conservative. The sensitivity range for the disability weights reflect the low and high range from the literature, whereas the point estimate of 0.02 reflects medical experts' judgement based on a relative weighting compared to other health endpoints. This implies the values provided by DEFRA could be up to 6 times higher if a different disability weight was chosen. It is clear that there is large uncertainty regarding the correct disability weight, but that the disability weight of 0.02 is likely to be an underestimate of the health costs. Lastly, the dose-response function for %HA for aviation noise that was used by DEFRA is likely to underestimate the %HA from aviation noise. This was revealed by an EEA report (EEA, 2010), which noted that recent studies indicated that the %HA from aviation noise at a given exposure was higher than that predicted by the function in the EC Position paper (European Commission, 2002). Therefore, the costs provided by DEFRA for aviation noise annoyance are likely to be an underestimate.

Figure 19 – Comparison of results: DEFRA and Bristow et al. (2015) (€$_{2016}$ per dB per household)



The major similarity between (Defra, 2014) and (Bristow, et al., 2015) (and some RP studies) is that findings suggest that noise nuisance is not linear, and is considered worse at higher noise levels. Furthermore, in line with the acoustic literature, the EBD findings support the hypothesis that noise nuisance from different types of transport is valued differently (e.g. aviation noise is worse than road noise).

Conclusion: Annoyance costs

The literature is not unanimous on which of the three methods, SP, RP or EBD, is the best. In previous editions of the Handbook, HEATCO's values were used, which were based on the SP method. At the time, these were the most recent, highest quality insights.
Although there has been extensive work in this field since the publication of earlier editions of this Handbook, the meta-analysis of SP studies by Bristow et al. (2015) is the major

revolutionary piece in this literature. Therefore, in this Handbook the values by (Bristow, et al., 2015) are used. These nuisance values are also based on the SP method, but their main advantage is that they increase with the noise level. This brings them in line with the most recent insights in literature, but also with the valuation figures used in practice in a range of European countries (e.g. Denmark, UK, Sweden). RP results are notoriously difficult to generalise, due to large differences between housing markets and an NSDI that is highly dependent on underlying assumptions. With our research spanning a large geographical area, we believe the use of SP is more appropriate in the valuation of noise than RP. Compared to EBD results, (Bristow, Wardman, & Chintakayala, 2015)'s results incorporate a larger share of the nuisance, are less likely to be a clear underestimate and are less sensitive to certain assumptions (e.g. disability weight). Therefore, we opted to use SP values in this study.

Although (Bristow, et al., 2015) only present annoyance values for road and aviation noise, we recommend applying their annoyance values for road and rail noise (see Section E.4 for a discussion of the rail bonus). We use a threshold value for annoyance of 50 dB(A), in line with recommendations from previous editions of the Handbook. Although it is widely known that noise nuisance also exists at lower levels of noise, e.g. (WHO, 2011) (EEA, 2010), it is currently unclear in how far the valuation studies present reliable values for lower levels of noise.

E.5.3 New evidence health costs

One can distinguish between two types of health effects of noise: the effects on the person himself (pain, discomfort, etc.), which can be valued using VOLYs (Value Of Life Year) or DALYs (Disability-Adjusted Life Year), and the effects on the rest of society (e.g. medical costs). The main method to calculate health costs uses the environmental burden of disease (EBD).

Costs to the person himself

There are two recent studies which have calculated health costs of noise to the person himself since the publication of the most recent edition of the Handbook: (Defra, 2014) and (Fraunhofer ISI & Infras, 2018). The studies differ in which health effects they take into consideration. As the WHO is the world-leading authority on health, we aim to align the health effects incorporated in this Handbook as much as possible with their latest publications. The latest WHO Systematic Reviews revealed a number of health effects from traffic noise for which evidence was considered at least of moderate quality (Section E.2). Between (Defra, 2014) and (Fraunhofer ISI & Infras, 2018), the health effects that Defra (2014) takes into consideration match the WHO findings best, although it leaves out the diabetes, obesity and cognition costs of noise (for which moderate quality evidence was found for certain transport modes). (Fraunhofer ISI & Infras, 2018) do not take into account the costs from noise exposure related strokes (although this is recommended by the WHO), but do take into account the costs from breast cancer and depression (which is not recommended by the WHO). Overall, we conclude that the study conducted by Defra (2014) aligns best with the WHO's most recent recommendations. Therefore, the findings from Defra will be used as a basis for calculating health related costs of noise to the person himself.

We make one minor modification to the health costs as calculated by Defra. Defra takes into account annoyance *and* sleep disturbance separately, although arguably there is some overlap between the two. Most of the annoyance will take place because of the sleep disturbance. Therefore, if individuals are well informed of the health effects of noise we can expect them to take sleep disturbance costs into account in their WTP/WTA values for annoyance shown in SP studies. HEATCO (2006) assumes that costs of sleep deprivation are already part of the annoyance costs of noise, and therefore do not need to be taken into account in the valuation of health costs. Previous editions of the Handbook also followed this approach. This method is deemed plausible and therefore also followed this study.

Medical costs

The medical costs of noise exposure are not included in Defra (2014). Under medical costs, we also consider the costs of productivity losses due to illness, e.g. working days lost and days lost due to reintegration into work. Therefore, we base our calculations of the medical costs on (HEATCO, 2006), where the medical costs due to noise were calculated to be 8% of the VOLY. We therefore use this rule of thumb to estimate the medical costs of noise and apply it to all the countries that we are considering.

Conclusion: Health costs

For health costs the values are based on Defra (2014), but adjusted to also incorporate the medical costs. The final values used in this Handbook are presented in Table 86.

Table 86 - Health costs used for the EU28 (€2016/person/dB/year) based on Defra (2014)

Transport mode	< 55 dB	55-59 dB	60-64 dB	65-69 dB	70-74 dB	> 75 dB
Road	3	3	6	9	13	18
Rail	3	4	6	9	13	18
Aviation	5	6	9	12	16	21

E.5.4 Conclusions

Since the previous editions of the Handbook (Infras, CE Delft, ISI & University of Gdansk, 2008) (Ricardo-AEA, TRT, DIW Econ & CAU, 2014), substantial research has been conducted on the external costs of noise. For **annoyance costs**, these new insights have resulted in a new set of cost values that will be used in this Handbook, based on (Bristow, et al., 2015). A particularly novel aspect of these values is that they increase with the noise level, reflecting the increased annoyance with higher levels of noise. For the **health costs**, a lot of research has focussed on identifying the correct health endpoints that are affected by noise. Unfortunately, there is no health cost study that incorporates all health effects for which evidence is considered at least 'moderate quality' by the WHO's latest systematic reviews. However, the costs by (Defra, 2014) best match the WHO's findings. Therefore, the values from (Defra, 2014) will be used and adapted to each of the countries considered in this study.

F Detailed assessment congestion costs

F.1 Introduction

This annex presents in detail the methodology used to estimate the road congestion costs (Annex F.2). Detailed results for road congestion costs per Member State are presented in Annex F.3 to F.7. Annex F.8 presents the findings on congestion and scarcity costs for other modes of transport.

F.2 Detailed discussion on effects of road congestion

The methodology is based on the model summarised in Figure 7 in Section 7.3.1, as it provides a sound theoretical background. Nevertheless, it should be taken into account that this model is a simplification.

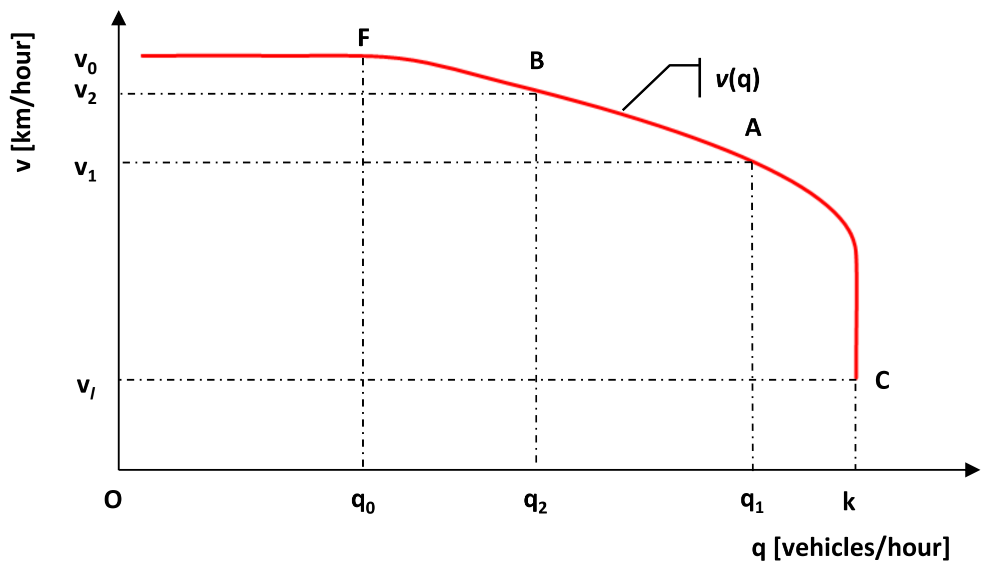
The model refers to a single link to which a specific speed-flow relationship applies, whereas in the real world, links belong to networks made of links with different features. Furthermore, in the model there is one demand function whereas in the real world there are several user categories with different preferences and willingness to pay. Since the different categories share the use of the network, the definition of the socially optimum demand level is not straightforward. For those reasons, cost estimates should necessarily be considered as approximations.

The approach to estimate the road congestion cost postulates a relationship between the speed v and the flow q on a road link (i.e., the quantity of vehicles passing through a transversal road section of the link in a unit of time).

The speed-flow relationship $v = v(q)$ (see Figure 20) is to be interpreted as follows. If the flow takes any value lower or equal to q_0, the vehicles travel at free-flow speed v_0. As the flow increases above the free-flow, say $F(q_0; v_0)$, the speed gradually decreases to points B or A. When the flow approaches the capacity of the link, say k at point C, the speed of the flow reduces to the lower limit v_l due to a local blockage[61].

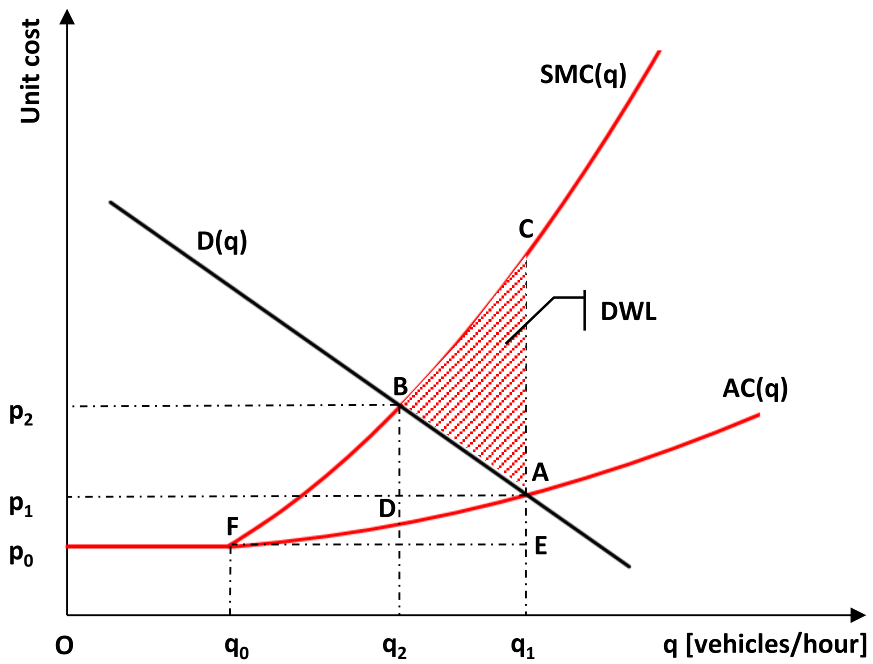
[61] According to road traffic theory, if the speed reduces significantly, less cars can pass through the local blockage, therefore the flow should decrease and the curve should return back towards the vertical axis, in form of a horizontally U-shape function. For the purpose of this model, the calculations have been developed only considering a traffic flow situation represented in the upper part of the speed-flow relationship (i.e., above point C).

Figure 20 - The speed-flow relationship



In Figure 21, the function $AC(q)$, representing the average travel cost borne by the road users, results from the product of the value of time, which is assumed to be constant across road users and the average travel time. If the flow takes any value lower or equal to q_0, the cost of travel is equal to p_0 and it corresponds to the cost of travel time, at free-flow speed. When q increases, the speed reduces, the travel time increases, and consequently $AC(q)$ increases.

Figure 21 - Road congestion depending on network conditions



The straight line $\mathrm{D(q)}$ is an inverse of a function representing the demand of usage of a road link, depending on the unit cost, expressed in monetary terms. At the point where functions $\mathrm{D(q)}$ and $\mathrm{AC(q)}$ intersect, an equilibrium is reached (i.e., point $\mathrm{A(q_1; p_1)}$) and the willingness to pay of the user is equal to the private cost borne.

The function $SMC(q)$ is the social marginal cost function, which is equal to the private cost $AC(q)$ plus the cost of the additional travel time, generated by the marginal vehicle that reduces the speed of all the other vehicles. The driver of the marginal vehicle experiences only his own travel time and not the effect of his decision on the travel times of the other drivers. Therefore, if an additional vehicle enters the flow, the total social cost is increased by:

$$\frac{dSC}{dq} = AC(q) + q \cdot \frac{dAC(q)}{dq}$$

In the equation above the first term is the 'private cost' of a single vehicle, while the second term is the external cost borne by the other users already in the flow due to the additional vehicle.

Including this external cost element, which is not considered by the single user, the social marginal cost curve is the relevant decision base. The point $B(q_2; p_2)$, where the functions $D(q)$ and $SMC(q)$ intersect, represents the optimal solution. Beyond this point, any additional vehicle generates a social cost higher than the social benefit[62].

F.2.1 Definition of the private costs curve

The private cost curve is assumed to reflect the monetary cost of driving time, namely the travel time. The time cost of driving increases as the average speed falls, i.e. as the traffic flow increases. A non-linear speed-flow function is applied to represent this relationship, namely as follows:

$$T = T_0 \cdot (1 + Par_A \cdot r^{Par_B})$$

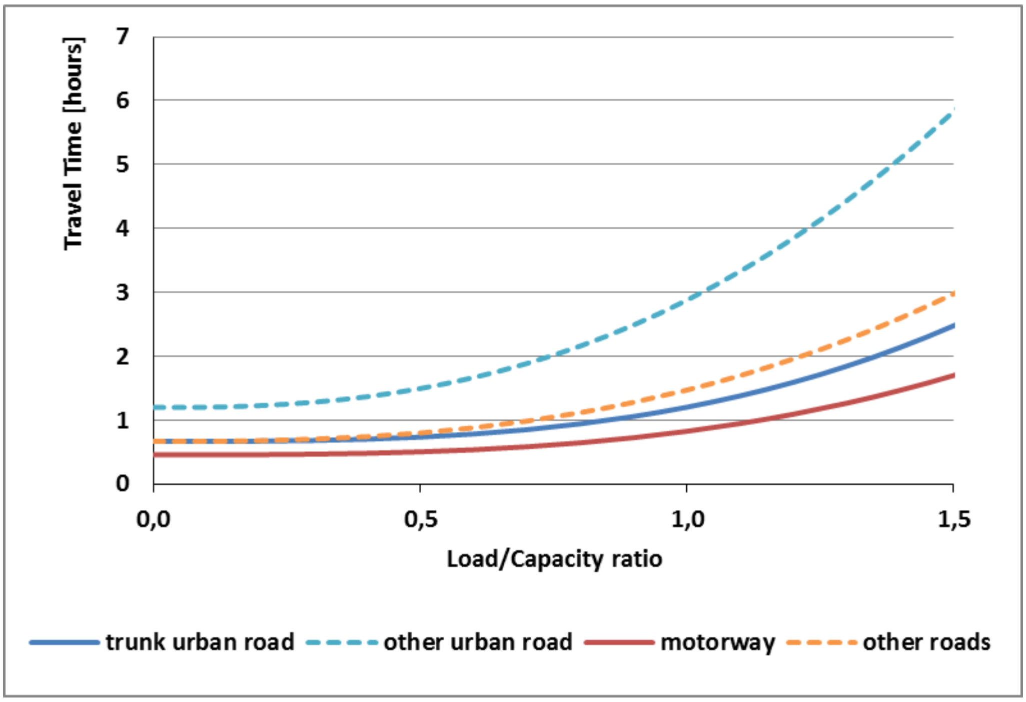
Where:

- T is the actual travel time;
- T_0 is the travel time in free flow conditions;
- r is the flow/capacity ratio;
- Par_A and Par_A are parameters of the function.

Different speed-flow functions have been implemented in order to differentiate between the road types (i.e., trunk urban road, other urban road, motorway and other non-urban roads) (see Figure 22).

62 To stimulate the user decisions to follow the SMC(q) function, the difference between average private costs and marginal social costs (i.e., the segment DB) has to be charged.

Figure 22- Example of speed-flow functions for different road types



F.2.2 Values of time

National values of time for cars and occupancy factors assumed within this Hanbook have been used to estimate the private (average) cost curve AC, in order to take into account that the delay is suffered by all individuals travelling in cars experiencing congestion and not only drivers.

National values of time for car and coach passengers have been estimated from the UK's Department for Transport (ARUP, 2015). Data for UK have been used to estimate values for the other countries based on GDP per capita (PPP adjusted) by country. Values of time for coach passengers are about 48% lower than the value of time of long distance car passengers. For coaches, the VOT of the driver has beed considered on the basis of the data available from Comité National Routier (2016) by country. The values of time applied for trucks in terms of commodity transported have been quantified building on those reported in deliverable 5 of the project HEATCO (2006) and Significance, VU University Amsterdam & John Bates Services (2012). Moreover, also the VOT of the driver has been considered in the analysis on the basis of the data available from Comité National Routier (2016) by country. More specifically, the values for road modes have been used (tonne per hour), assuming the average load factor by country for heavy duty vehicles (e.g. about 13.6 tonnes per vehicle for HGV on average in EU28 countries and 0.7 tonnes per vehicle for LCV) and the VOT of the driver has been added to the estimation in order to the measure the VOT per vehicle. For LCV it has been assumed that the VOT of the driver is lower than for HGV, assuming a lower cost of labour due to lower skills requested. The GDP deflator has been applied to update all the values to Euro 2016.

Table 87 - Value of time by purpose and country for short and long distance trips by car (Euro2016/hour per person)

Country	Short distance* (urban)		Long distance* (inter-urban)	
	Commuting - business	Personal	Commuting - business	Personal
Austria	16.9	7.8	19.8	7.8
Belgium	15.6	7.2	21.2	7.2
Bulgaria	6.5	3.0	8.5	3.0
Cyprus	11.0	5.1	12.5	5.1
Croatia	8.0	3.7	9.6	3.7
Czech Republic	11.6	5.4	14.0	5.4
Denmark	16.4	7.6	20.7	7.6
Estonia	10.0	4.6	12.1	4.6
Finland	14.5	6.7	20.6	6.7
France	13.8	6.4	15.7	6.4
Germany	16.4	7.6	20.0	7.6
Greece	9.0	4.1	11.4	4.1
Hungary	9.0	4.1	11.7	4.1
Ireland	24.2	11.2	28.3	11.2
Italy	12.8	5.9	16.7	5.9
Latvia	8.6	4.0	10.6	4.0
Lithuania	10.0	4.6	12.1	4.6
Luxembourg	34.2	15.8	38.9	15.8
Malta	12.5	5.8	15.3	5.8
Netherlands	16.9	7.8	22.2	7.8
Poland	9.1	4.2	10.4	4.2
Portugal	10.3	4.8	12.4	4.8
Romania	7.7	3.6	8.8	3.6
Slovakia	10.2	4.7	13.4	4.7
Slovenia	11.0	5.1	13.2	5.1
Spain	12.1	5.6	15.0	5.6
Sweden	16.4	7.6	19.6	7.6
United Kingdom	14.3	6.6	17.3	6.6
Norway	19.7	9.1	24.0	9.1
Switzerland	21.4	9.9	26.2	9.9

Short distance: less than 32 km.

Long distance: more than 32 km.

Source: TRT elaboration on UK Department for Transport (ARUP, 2015).

Table 88 - Value of time for freight road long distance trips by country (Euro2016/hour per tonne)

Country	Value per tonne	Value per HGV/coach driver
Austria	2.1	22.5
Belgium	1.1	33.4
Bulgaria	0.7	8.0
Cyprus	1.5	13.2
Croatia	0.8	10.6
Czech Republic	1.4	10.2
Denmark	2.0	21.9
Estonia	1.1	13.3
Finland	2.6	19.3
France	1.6	29.8
Germany	2.0	20.9
Greece	1.9	11.9
Hungary	1.4	9.6
Ireland	1.4	32.3
Italy	1.4	28.1
Latvia	1.1	11.4
Lithuania	1.1	8.9
Luxembourg	2.7	28.2
Malta	1.7	19.5
Netherlands	1.7	22.5
Poland	1.4	10.0
Portugal	1.8	13.2
Romania	0.8	9.0
Slovakia	1.2	11.3
Slovenia	1.8	13.1
Spain	1.8	19.5
Sweden	2.4	21.8
United Kingdom	1.9	19.0
Norway	4.2	26.2
Switzerland	1.3	28.5

Source: TRT elaboration on HEATCO project, Significance, VU University Amsterdam, John Bates Services (2012) and Comité National Routier (2016)

F.2.3 Definition of marginal cost curve

The social cost curve has been derived from the private (average) cost curve, using the first derivative of the expression reported above, namely:

$$SMC = C_0 + C_0 \cdot Par_A \cdot Par_B \cdot r^{(Par_B - 1)}$$

where $C_0 = T_o \cdot VOT$.

F.2.4 Definition of demand curve

The demand curve has been estimated using demand elasticity parameters[63] starting from the initial demand (i.e., the level of demand corresponding to the assumed level of capacity occupancy).

Given the speed flow curves, the load/capacity ratio producing the reported delay could be calculated separately for each road type during peak and off-peak periods. Then, the following function has been used to estimate the flow/capacity ratios for alternative values of cost (i.e., of travel time):

$$r = m \cdot AC + k$$

Where:
- r is the flow/capacity ratio;
- AC is the average cost of driving (i.e., time cost of driving only);
- m is the cost elasticity;
- k is a constant parameter defining the position of the demand curve.

Cost elasticity parameters m have been defined in literature, in particular Littman (2011) and Oum et al. (1990). Different elasticity parameters have been used for peak and off-peak periods[64]. Values have been estimated as weighted average of values by trip purpose, considering the composition of trips in different periods. Values used are reported in Table 89.

Table 89 - Values of cost elasticities assumed

Mode	Elasticity urban demand	Elasticity inter-urban demand
Car - Commuting/business trips	-0.49	-0.56
Car - Personal trips	-0.58	-0.67
Truck	n. a.	-0.30
Coaches	n. a.	-0.30

Source: TRT elaboration on literature data.

F.2.5 Calculation of the optimal demand level

In order to estimate the deadweight loss, point B of Figure 21 is also required. To identify this point, where the demand curve and the social cost curves cross, an iterative process has been applied. The value of the load/capacity ratio r^* such that the social marginal costs curve provides a marginal cost corresponding to the same load/capacity ratio according to the demand curve.

[63] Demand elasticity parameters are defined here as a measure of the relationship between a change in the transport demand (i.e. the number of trips by car) and a change in the related cost (in this case the private cost per trip). As an example, a value of the elasticity parameter of -0.5 means that an increase of cost by 20% is reflected in a decrease of transport demand by -10%.

[64] It is assumed that during peak period about 49% of trips is commuting and the residual is for other purposes, instead during off-peak the commuting trips are about 22%.

F.2.6 Estimation of total deadweight loss

Using the elements obtained in the steps above, the value of deadweight loss[65]. is obtained as the area of the triangle ABC in Figure 21 using the following equation:

$$DWL^{*} = (r_1 - r^{*}) \cdot \frac{(SC_1 - PC_1)}{2}$$

Where:

- $r^{*}$is the optimal load/capacity ratio;
- r_1 is the load/capacity ratio in the assumed congestion conditions;
- SC_1 is the social cost in the assumed congestion conditions;
- PC_1 is the private cost in the assumed congestion conditions.

F.2.7 Estimation of deadweight loss per vkm

The value of deadweight loss DWL^{*} is related to one vehicle travelling for 1 km in congestion. Based on assumed road capacity by road type and load (i.e., near capacity, congested, over-capacity), the deadweight loss per vkm DWL has been estimated as follows:

$$DWL = DWL^{*} \cdot \frac{L_r}{V_r}$$

Where:

- L_r is the capacity of the road (i.e., by road type r);
- V_r is the vkm of the road (i.e., by road type r) in the assumed congestion conditions (i.e., near capacity, congested, over-capacity).

$$V_r = L_r \cdot r_1$$

Where:

r_1 is the flow-capacity ratio (v/c) in the assumed congestion conditions.

The estimation has been made differentiating peak and off-peak periods; then, the average daily value has been estimated based on an assumption of the amount of trips during peak/off-peak periods.

Table 90 presents the differentiation of the deadweight loss per vkm on congested network with respect to context and road type, and the level of utilisation of the capacity of the road link. Traffic situations are identified based on the volume to capacity ratio of a traffic link. It is assumed that ‘near capacity’ is related to v/c ratios between 0.8 and 1, ‘congested’ refers to v/c ratios between 0.8 and 1.0, while ‘over capacity’ is considered when v/c ratio is above 1.2.

[65] As general remark, it is worth noting that the total external cost of road congestion coincides with the area FCA and that the area FBA is the part of the total external cost which is already accepted by the users (they have a willingness to pay higher than the cost borne). Therefore, the area FBA is neither mentioned in the literature, nor commonly used in developing empirical applications to estimate road congestion cost, which is estimated in terms of delay cost and deadweight loss, as done in this version of the handbook.

Table 90 - EU28 Deadweight loss per vkm of road transport on congested network

Vehicle category	Traffic situation	Urban area		Inter-urban area	
		Trunk roads	Other urban roads	Motorway	Other roads
Passenger transport (€-cent/vkm)					
Passenger car	Over capacity	3.8	7.6	3.7	5.7
	Congested	2.6	6.5	2.5	4.7
	Near capacity	1.5	4.7	1.4	3.2
Coach	Over capacity	n.a.	n.a.	28.4	35.3
	Congested	n.a.	n.a.	19.6	28.8
	Near capacity	n.a.	n.a.	10.9	19.6
Freight transport (€-cent/vkm)					
HGV	Over capacity	n.a.	n.a.	10.9	13.5
	Congested	n.a.	n.a.	7.5	11.0
	Near capacity	n.a.	n.a.	4.2	7.5

F.2.8 Estimation of delay cost per vkm

Delay congestion costs per vkm IC are estimated by applying values of travel time and the average vehicle occupancy factors to the amount of delay estimated from the application of speed-flow functions.

$$IC = (T - T_0) \cdot VOT \cdot OF$$

Where:
- T is the actual travel time in the assumed congestion conditions;
- T_0 is the travel time in free flow conditions;
- VOT is the value of travel time;
- OF is the occupancy factor.

The estimation has been made differentiating peak and off-peak periods; then, the average daily value has been estimated based on the assumption of the amount of trips during peak/off-peak periods.

Table 91 presents the differentiation of the delay costs per vkm on congested network with respect to context and road type, and level of utilisation of the capacity of the road link. Traffic situations are identified based on the volume to capacity ratio of a traffic link: it is assumed that 'near capacity' is related to v/c ratios between 0.8 and 1.0, while 'over capacity' is considered when v/c ratio is above 1.2.

Table 91 - EU28 Delay costs per vkm of road transport on congested network

Vehicle category	Traffic situation	Urban area		Inter-urban area	
		Trunk roads	Other urban roads	Motorway	Other roads
Passenger transport (€-cent/vkm)					
Passenger car	Over capacity	25.7	73.4	23.5	47.7
	Congested	12.4	38.8	11.3	24.7
	Near capacity	5.1	17.8	4.6	11.1
Coach	Over capacity	n.a.	n.a.	254.8	427.7
	Congested	n.a.	n.a.	122.9	221.9
	Near capacity	n.a.	n.a.	50.3	99.4
Freight transport (€-cent/vkm)					
HGV	Over capacity	n.a.	n.a.	97.6	163.9
	Congested	n.a.	n.a.	47.1	85.0
	Near capacity	n.a.	n.a.	19.3	38.1

F.2.9 Methodology to estimate yearly road congestion costs

Marginal congestion costs per vkm and delay cost per vkm have been used to estimate the respective yearly road congestion costs in the EU. It should be noted that this cost is an estimation of the monetary equivalent of additional travel time rather than a true financial cost borne by individuals or companies. With a few exceptions (e.g., higher fuel consumption, clients of taxicabs paying a higher charge because of longer travel time due to congestion, companies delivering freight that have to use more vehicles — and therefore drivers — to complete consignment in due time), travel time wasted in congestion does not entail any monetary expenditure or missing revenues.

Also, interpreting the estimation in monetary terms of congestion cost as an economic benefit that individuals could enjoy if congestion were removed is actually incorrect.
As pointed out by Goodwin (2004): "*The implied annual dividend [...] to be distributed to each family is a fiction. It is calculated by comparing the time spent in traffic now, with the reduced time that would apply if the same volume of traffic was all travelling at free flow speed, and then giving all these notional time savings the same cash value that we currently apply to the odd minutes saved by transport improvements. But this could never exist in the real world — not for reasons of practical difficulty, but because it is internally inconsistent. If all traffic flowed at free flow speed, we can be quite certain there would be more of it, at least part of the time saved would be spent on further travel, and further changes would be triggered whose value is an unexplored quality. It is apparently a precise answer to a phantom question*".

The estimation has been made separately for urban and inter-urban congestion given the different type of information available.

F.2.10 Estimation of yearly road urban congestion cost

Yearly urban congestion costs were estimated building on the information provided by TomTom data on about 212 cities in Europe. Data is provided on the level of congestion and road network length by road type (i.e., trunk urban road, other urban road), average delay per day (based on two 30 minute peak period journeys per day) and total accumulated delay per year (related to peak period journeys).

The two road types (i.e., urban trunk roads and other urban roads) are differentiated according to the data already available from the TomTom dataset. The purpose of this differentiation is to obtain different speed-flow functions. Peak and off-peak periods are separated to take into account that trip purposes are not the same during different periods of the day and therefore that values of time and elasticities of demand are also variable. This segmentation is not directly available in the TomTom dataset so the data has been elaborated to derive wasted time in congestion separated for peak/off peak periods crossed with urban trunk roads/other urban roads.

The amount of delay on urban trunk roads (and other urban roads) during off-peak periods has been estimated in two steps. First, given the ratio between the congestion index and the average congestion index during peak periods the daily amount of delay on urban trunk roads (other urban roads) has been estimated. Second, the part of this daily delay occurring during off-peak periods has been estimated building on the shares of trips in peak and off-peak (based on travel surveys statistics). Basically, given these shares and given the amount of delay during peak periods the amount of delay in off-peak time has been computed to sum the two components to reproduce the total daily delay (on urban trunk roads and other urban roads respectively).

Building on the information above, the amount of congested network by road type and time period CN_{rp} has been estimated:

$$CN_{rp} = \frac{DT_{rp}}{T_{cr} - T_{0r}}$$

Where:
- DT_{rp} is the average delay per day by road type r and time period p;
- T_{cr} is the actual travel time in the assumed congestion conditions c;
- T_{0r} is the travel time in free flow conditions by road type r.

The most representative congestion conditions for each city (based on TomTom data) have been used to estimate total cost per vehicle, by multiplying the related deadweight loss and delay cost per car vkm (i.e., EC_{pr} and IC_{pr}, differentiated by time period and road type) by the related estimated congested network (during peak and off-peak periods).

Finally, total yearly costs in the urban context (i.e., IC and EC) have been estimated using the population size (i.e., P), the share of individuals travelling (i.e., $shTP$) and the car share (i.e., $shCar$), assuming 230 work days per year[66].

$$IC = P \cdot shTP \cdot shCar \cdot \sum_{pr} IC_{pr} \cdot 230$$
$$EC = P \cdot shTP \cdot shCar \cdot \sum_{pr} EC_{pr} \cdot 230$$

Car share data has been defined based on information reported in the EPOMM Modal Split Tool (TEMS)[67] integrated with local sources where data from this tool was not available. The share of population travelling is estimated as 76% of population living in the city, according to AUDIMOB data for 2013.

66 This value is consistent with assumptions reported for the estimation of the TomTom congestion index.

67 See also http://www.epomm.eu/tems/

This methodology provided urban congestion costs related to passenger cars for the European cities included in TomTom data. The generalisation of results to all urban areas for each country was made as explained below.

F.2.11 Methodology for cities with more than 50,000 inhabitants

First of all, in order to obtain a set of data comparable among different cities in different countries, marginal costs have been re-estimated using an average value of time and an average occupancy factor for all EU. This set of costs has been used for a statistical analysis aimed at identifying correlations between congestion cost per capita and population of the cities by class.

It was found that the higher the population size class the city belongs to, the higher the deadweight congestion cost per vehicle (see Table 92).

Table 92 - Average yearly delay cost and deadweight loss per capita depending on city population size: TomTom sample data (EURO$_{2016}$/capita)

City population size	Average delay cost per capita	Average Deadweight lossper capita
More than 5 million	898.5	165.0
2 to 5 million	806.6	145.5
1 to 2 million	754.1	134.4
500,000 to 1 million	734.4	130.2
250,000 to 500,000	724.6	128.2
100,000 to 250,000	719.3	127.0

Source: TRT estimation on TomTom data.

Since we are estimating congestion costs in cities, we considered not only national differences of values of time, but also regional differences in terms of average income per capita. The average values have been scaled to consider (i) the national values of time (see Table 86) and (ii) the ratio between regional and national GDP per capita. Therefore, the estimation of urban congestion cost has been made assuming that the opportunity cost of time depends on local features and particularly economic activity.

These values of congestion cost per capita by NUTS3 region have then been applied to all related cities with at least 50,000 inhabitants. The list of cities has been compiled based on information collected from different sources, e.g. the website City Population as well as national statistical offices. The list includes about 1,275 cities in 30 European countries (i.e., EU28 plus Switzerland and Norway).

F.2.12 Methodology for cities with less than 50,000 inhabitants

It is reasonable to expect that some congestion occurs also in cities with less than 50,000 inhabitants, however extending the dataset to cities larger than e.g. 15,000 inhabitants would have been too complex given the number of urban areas of this size in Europe.
A simplified approach was adopted to generalise urban congestion costs also to cities below the threshold of 50,000 inhabitants.

The simplified approach consisted of estimating the number of additional urban areas to consider in each NUTS3 zone. Two elements have been used for this estimation. First, the total amount of population in the NUTS3 zone compared to the amount of population in the cities with more than 50,000 inhabitants located in the same zone. Intuitively if these cities explain a large share of total population of the NUTS3 it is likely that only a few or even no cities between 15,000 and 50,000 inhabitants exist in that zone. Vice-versa, if the cities above 50,000 inhabitants explain only a limited share of total population, a higher number of smaller cities can be expected.

The second element was the typology of NUTS3 according to the classification urban/mixed/rural. In rural areas, cities tend to be smaller and so a lower number of urban areas between 15,000 and 50,000 inhabitants can be expected for a given share of population not explained by the cities above 50,000 inhabitants. NUTS3 population was extracted from the Eurostat database. The classification of NUTS3 regions in three categories: predominantly urban, predominantly rural, mixed is also provided by Eurostat.

The cities with at least 50,000 inhabitants have been associated to the NUTS3 zone they belong. Then, for each NUTS3 region, the sum of the population living in cities with at least 50,000 inhabitants has been compared to the total population of the region. Depending on the share of population living in the city/cities with more than 50,000 inhabitants in each NUTS3 region and the category of the region itself, different rules have been applied to estimate how many additional urban areas should be considered for the generalisation of urban congestion cost.

Using the average congestion costs per capita related to passenger cars in a NUTS3 region, total urban congestion cost by NUTS3 region was quantified. An additional assumption made has been that in cities with less than 50,000 inhabitants, congestion occurs only in the peak period of the day.

F.2.13 Estimation of yearly marginal congestion cost for inter-urban roads

The quantification of traffic experiencing congestion on inter-urban roads has been carried out building on two main sources. One source was a map of the congested spots on the European inter-urban road network provided by JRC Sevilla. This map identified spots where road traffic is delayed in the most congested peak hours because of traffic and, for each spot, provided the amount of delay (in terms of additional time per km). The map was drawn using real traffic data for the year 2013.

The map was very helpful to identify where congestion occurs and the range of its severity, however this source alone did not allow to quantify the amount of demand involved in congestion. This further element could be estimated by means of parameters used in the TRUST network model. TRUST is a transport network model covering the whole of Europe developed by TRT (see the following Box for details).

In TRUST the road network is classified into different link types (e.g., motorways, dual carriageways roads, etc.). Each link type is associated to specific features; in particular speed-flow functions. Speed flow functions link traffic on one road to the time required to travel onto the road itself. They differ according to road types, for instance urban roads free flow speed is disturbed already for relatively low level of traffic whereas on motorways speed is maintained longer but is then more rapidly reduced when traffic approaches capacity.

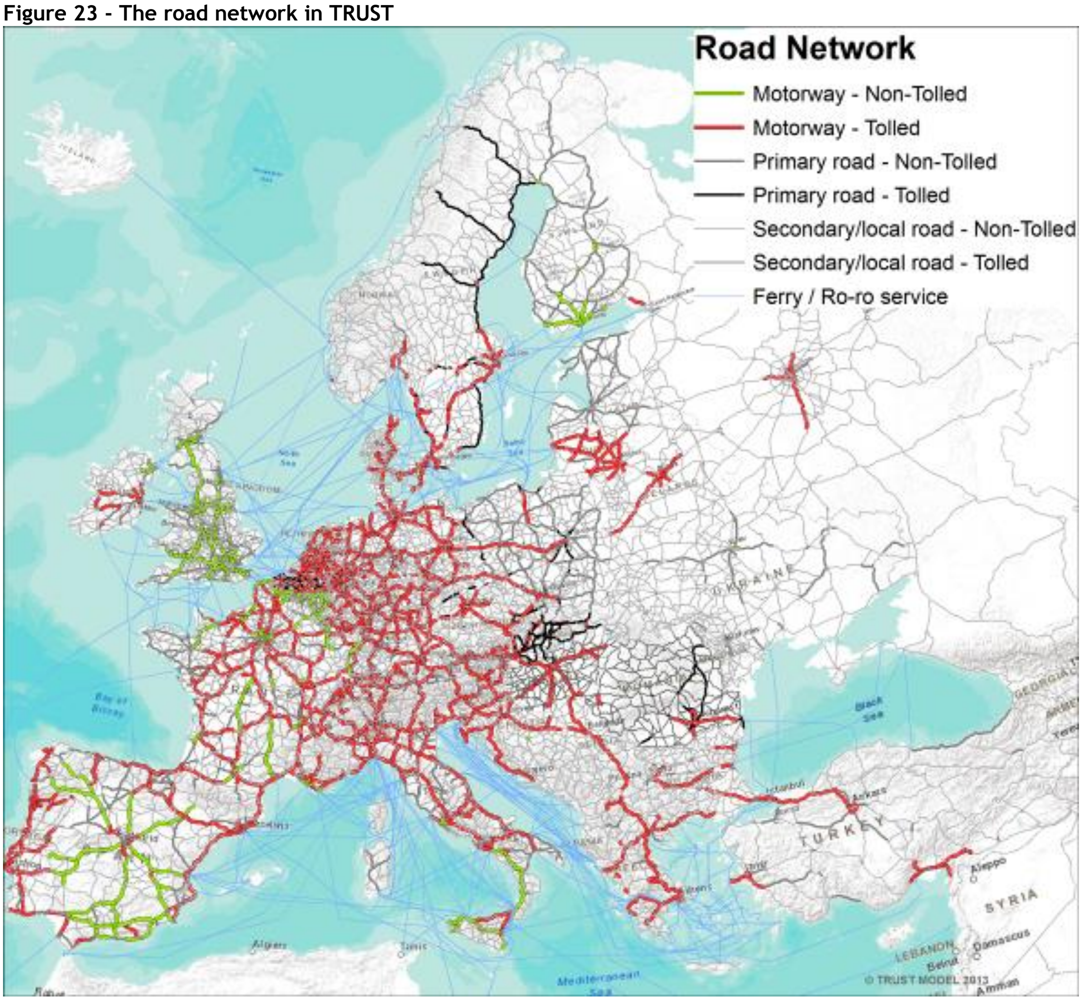
The TRUST model

TRUST (TRansport eUropean Simulation Tool) is a transport network model developed by TRT in the MEPLAN software environment. TRUST is a transport network model for the assignment of Origin-Destination matrices at the NUTS3 level of detail for passenger and freight demand. TRUST covers the whole Europe, including Accession and Neighbouring countries.

Road as well non-road transport modes are dealt with in TRUST. The road network includes all the relevant links between the NUTS3 regions, i.e. motorways, primary roads as well as roads of regional and sub-regional interest. Also ferry connections (i.e., ro-ro services) between European regions are explicitly modelled with their travel time and fare. Road network links are separated in different classes, each with specific features in term of capacity, free-flow speed and toll.

The main output of TRUST is the load on road network links in terms of vehicles per day and on non-road links in terms of either trips or tonnes per day. The model is calibrated to reproduce tonnes-km and passengers-km by country consistent to the statistics reported in the Eurostat Transport in Figures pocketbook net of intra-NUTS3 demand (available from ETISplus), which is not assigned to the network. Using load as an input parameter and emissions factors the model also provides emissions by link for NO_x, PM and CO. Figure 23 shows the road network modelled in TRUST.

Figure 23 - The road network in TRUST



The TRUST model uses the most recent data made available by the ETISplus[68] project. Apart the features of the network links (speed, capacity, etc.), the main parameters used in TRUST are:

- transport costs by mode;
- speed-flow functions;
- values of travel time;
- average fuel consumption and emission factors (for road modes).

The TRUST model has been successfully applied for the assessment of the Eurovignette directive on behalf of the European Commission.

Using the range of delay[69] reported on the map of the congested spots and the speed-flow function of the roads where the spots are located, it was possible to estimate the level of occupancy of each spot in peak time, i.e. the amount of vehicles (in terms of Passenger Cars equivalent Units – PCEs) experiencing congestion in the most congested peak hour.

Traffic on road links includes several vehicle types: cars, trucks, etc. Since the congestion cost associated with each type is different, a segmentation of the estimated loads has been estimated. Two main classes of road users have been considered, namely: cars and trucks. The share of demand belonging to each class has been estimated making reference to the segmentation of traffic on each link assigned by the TRUST model. Indirectly, coaches have also been considered in the analysis based on the assumption that the share of interurban coach vkm with respect to car and truck vkm (available as data by country) could be used to estimate the related traffic on the congested sport.

The most congested peak hour is when motorists experience the highest delays, however there are other peak and off-peak periods when some congestion occurs. In order to estimate the overall cost of inter-urban congestion also delays outside the most congested peak hours should be estimated. This task was addressed using representative road load profiles for passenger cars and trucks during the day in different countries (i.e. Italy, France, United Kingdom and the Netherlands).

Road profiles describe how traffic changes over a 24-hour period. Of course in principle each road has its own profile but the distribution of traffic during the day is very similar for different roads and also in different countries (although peak time can be slightly different according to local habits about e.g. working time).

Using these profiles and using the estimated load in the most congested peak time, it has been possible to estimate the load in each hour. Given the capacity of the road (taken from TRUST) and considering the sum of all vehicle types (in terms of Passenger Cars equivalent Units – PCEs) the load/capacity ratios have been estimated for each link and hour.
All vehicles travelling in hours with a load/capacity ratio higher than 1 have been considered experiencing congestion (congested with load/capacity ratio up to 1.2 and over capacity with load/capacity ratio above 1.2); furthermore, also vehicles travelling in hours with a load/capacity ratio between 0.75 and 1 have also been considered experiencing congestion (near capacity).
After this process, the total number of vehicles incurring congestion on the inter-urban European networks in an average day has been obtained for each vehicle type (i.e., car and

68 ETISplus provides a set of data including networks, matrices, etc. to serve for the development of transport modelling at the European level.

69 Data has been used in terms of classes of delay instead of punctual values due to some discrepancies occurring when joining the TRUST network with the JRC network, which are not perfectly matching.

truck). Vkms in congestion by vehicle type have been estimated multiplying loads by length of congested network on a link level. The estimation of the amount of yearly traffic is made assuming 230 work days per year.

In order to estimate the amount of coaches experiencing congestion on inter-urban roads, the amount of vkm has been estimated on the basis of assumptions on the share of coaches traffic with respect to car traffic by country (taken from the ASTRA model).

F.2.14 Estimation of yearly congestion cost for other road transport categories

With reference to congestion costs for trucks at the urban level, due to lack of information, the methodology applied for cars cannot be replicated. Therefore, in order to provide some information to also cover this aspect, a simplified approach has been applied, based on the estimation of congestion costs for cars, Value of Times by mode and data on vkm at urban level for LCVs and HGVs (estimated/collected within this Handbook).

A similar simplified approach is also applied for LCVs at inter-urban level. The estimation has been based on the value of congestion costs for cars, the Value of Time and data on vkm at inter-urban level (estimated/collected within this Handbook).

F.2.15 International comparisons of urban congestion costs

The methodology for the estimation of urban congestion costs has been applied for international comparison to the following non-EU regions: British Columbia and Alberta for Canada and California and Missouri for US, respectively. The methodology was built on TomTom data on urban congestion of 13 cities of the above mentioned regions, following the same steps applied for the European context.

Although the sample of cities was limited in this case, a statistical analysis has been performed to estimate the correlation between congestion cost per capita and city population size (see Table 93). These values of road congestion cost per capita have then been applied to all related cities with at least 20,000 inhabitants, multiplying the values by the population data[70].

The estimation of urban congestion costs for Japan followed the same approach, although TomTom data was not available. Another congestion index, built on top of the traffic layer within Google Maps, has been used for the city of Tokyo. The index has been adapted to the TomTom format following the comparison of the data of European cities available in both Google Maps and TomTom format.

The trend of the correlation between congestion cost per capita and city population size of North-America has been used to estimate the values for Japan (e.g. average delay cost per capita for cities between 1 to 2 million inhabitants is about 43% less than the average cost for cities with more than 5 million inhabitants). These values of road congestion cost per capita have then been applied to all related cities above 500,000 inhabitants, multiplying the values by the population data[71].

70 For Canada:"Population and dwelling counts highlight tables, 2016 census". Statistics Canada For US, the 2010 US Census.

71 For Japan: Population data reported by Prefectural Governement.

Table 93 - Average yearly delay cost and deadweight loss per capita depending on city population size in non-EU regions: TomTom sample data (EURO$_{2016}$/capita)

City population size	Average delay cost per capita	Average Deadweight loss per capita
More than 5 million	1,918.7	275.5
2 to 5 million	1,396.7	228.5
1 to 2 million	1,098.4	201.7
500,000 to 1 million	986.5	191.6
250,000 to 500,000	930.6	186.6
100,000 to 250,000	900.8	183.9

Source: TRT estimation on TomTom data.

Table 94 reports the input parameters used for Europe and the non-EU regions under analysis in terms of Value of Time and average car occupancy factor.

Table 94 - Passenger Car Value of Time and average occupancy factor in EU28 and non-EU regions[72]

Context	Short distance		Average car occupancy factor
	Commuting - business	Personal	
	Euro$_{2016}$/hour per person		Persons/vehicle
EU28	13.3	6.1	1.7
Canada	7.7	7.0	1.5
US	11.3	10.8	1.7
Japan	12.3	10.3	1.5

Table 95 reports total urban congestion costs and urban congestion costs per capita for cars in Europe and in the non-EU regions under analysis.

Table 95 - Car urban congestion costs in EU28 and non-EU regions

Context	Total costs		Average costs per capita	
	Delay costs	Deadweight loss costs	Delay costs	Deadweight loss costs
	Billion €		€/year per capita	
EU28	172	30.0	337.2	58.6
Canada*	5	0.9	767.7	149.2
US*	64	10.9	1,840.6	314.3
Japan*	22	4.7	493.0	105.5

* Canada: Estimations for Alberta and British Columbia.

* USA: Estimations for California and Missouri.

* Japan: Estimations for cities above 500,000 inhabitants.

[72] For Canada:"The cost of urban congestion in Canada, Transport Canada Environmental Affairs 2006". For US: the National Household Travel Survey (NHTS) and US department of transportation. For Japan: "Valuation of travel time saving With revealed preference data In Japan: further analysis."

F.3 Detailed estimated congestion costs by country - Total costs generated estimated using the simplified approach

Table 96 - Total delay congestion costs generated by road modes, estimated using the simplified approach (billion Euro/year, in Euro2016)

Country	Urban				Inter-urban			
	Car	LCVs	Trucks (HGV)	Coaches	Car	LCVs	Trucks (HGV)	Coaches
EU28	160.775	46.462	11.561	3.947	35.276	9.022	3.034	0.528
Austria	1.893	0.736	0.138	0.040	0.618	0.211	0.037	0.013
Belgium	4.639	0.927	0.164	0.178	2.648	0.527	0.142	0.040
Bulgaria	1.278	0.088	0.126	0.055	0.078	0.006	0.008	0.002
Croatia	0.744	0.274	0.062	0.013	0.059	0.019	0.004	0.001
Cyprus	0.263	0.124	0.008	0.013	-	-	-	-
Czech Republic	2.120	0.591	0.333	0.072	0.265	0.076	0.051	0.012
Denmark	1.374	0.525	0.098	0.035	0.614	0.248	0.049	0.012
Estonia	0.223	0.025	0.022	0.009	0.050	0.005	0.005	0.002
Finland	1.763	0.313	0.057	0.047	0.135	0.024	0.010	0.002
France	17.196	5.731	0.588	0.374	9.481	3.836	0.436	0.127
Germany	30.970	4.601	2.711	0.417	4.790	0.340	0.366	0.064
Greece	3.225	0.639	0.133	0.095	0.419	0.101	0.021	0.013
Hungary	1.319	0.544	0.230	0.084	0.273	0.096	0.061	0.019
Ireland	3.516	3.825	0.055	0.225	0.982	0.399	0.034	0.013
Italy	19.032	5.799	0.886	0.683	4.010	0.981	0.244	0.059
Latvia	0.417	0.068	0.082	0.012	0.024	0.003	0.004	0.001
Lithuania	0.612	0.169	0.123	0.017	0.030	0.005	0.012	0.000
Luxembourg	0.314	0.388	0.048	0.015	0.203	0.250	0.050	0.004
Malta	0.062	0.011	0.020	0.002	-	-	-	-
Netherlands	6.091	3.129	0.350	0.052	1.234	0.267	0.119	0.004
Poland	7.066	1.477	2.042	0.311	1.966	0.384	0.705	0.057
Portugal	3.231	2.980	0.125	0.044	0.929	0.153	0.054	0.005
Romania	4.332	0.852	0.590	0.257	0.533	0.112	0.078	0.013
Slovakia	0.631	0.170	0.156	0.025	0.163	0.045	0.049	0.005
Slovenia	0.248	0.068	0.037	0.005	0.091	0.022	0.012	0.002
Spain	13.469	3.976	0.802	0.259	2.818	0.132	0.243	0.037
Sweden	4.743	1.192	0.208	0.113	0.243	0.061	0.023	0.003
United Kingdom	30.002	7.239	1.368	0.494	2.622	0.719	0.218	0.019
Norway	1.516	0.672	0.072	0.029	0.210	0.093	0.024	0.002
Switzerland	1.882	0.251	0.091	0.021	1.069	0.123	0.044	0.012

Table 97 - Total deadweight loss generated by road modes, estimated using the simplified approach (billion Euro/year, in Euro$_{2016}$)

Country	Urban				Inter-urban			
	Car	LCVs	Trucks (HGV)	Coaches	Car	LCVs	Trucks (HGV)	Coaches
EU28	28.026	7.988	2.020	0.676	5.518	1.439	0.453	0.082
Austria	0.341	0.132	0.025	0.007	0.099	0.034	0.006	0.002
Belgium	0.729	0.146	0.026	0.028	0.455	0.091	0.025	0.007
Bulgaria	0.222	0.015	0.022	0.010	0.008	0.001	0.001	0.000
Croatia	0.131	0.048	0.011	0.002	0.008	0.003	0.001	0.000
Cyprus	0.046	0.022	0.001	0.002	-	-	-	-
Czech Republic	0.378	0.105	0.059	0.013	0.033	0.009	0.006	0.001
Denmark	0.242	0.093	0.017	0.006	0.120	0.048	0.010	0.002
Estonia	0.040	0.004	0.004	0.002	0.005	0.001	0.000	0.000
Finland	0.315	0.056	0.010	0.008	0.023	0.004	0.002	0.000
France	3.039	1.013	0.104	0.066	1.556	0.628	0.073	0.021
Germany	5.490	0.816	0.481	0.074	0.711	0.051	0.055	0.009
Greece	0.581	0.115	0.024	0.017	0.085	0.021	0.004	0.003
Hungary	0.232	0.096	0.040	0.015	0.034	0.012	0.008	0.003
Ireland	0.454	0.493	0.007	0.029	0.111	0.047	0.005	0.002
Italy	3.406	1.038	0.158	0.122	0.679	0.165	0.042	0.011
Latvia	0.073	0.012	0.014	0.002	0.003	0.000	0.000	0.000
Lithuania	0.107	0.029	0.022	0.003	0.004	0.001	0.002	0.000
Luxembourg	0.053	0.066	0.008	0.003	0.034	0.042	0.009	0.001
Malta	0.010	0.002	0.003	0.000	-	-	-	-
Netherlands	1.069	0.549	0.061	0.009	0.223	0.048	0.022	0.001
Poland	1.250	0.261	0.361	0.055	0.222	0.043	0.080	0.006
Portugal	0.574	0.529	0.022	0.008	0.142	0.025	0.009	0.001
Romania	0.630	0.124	0.086	0.037	0.049	0.011	0.007	0.001
Slovakia	0.110	0.030	0.027	0.004	0.020	0.006	0.006	0.001
Slovenia	0.043	0.012	0.006	0.001	0.015	0.004	0.002	0.000
Spain	2.439	0.720	0.145	0.047	0.423	0.021	0.040	0.006
Sweden	0.837	0.210	0.037	0.020	0.043	0.011	0.004	0.000
United Kingdom	5.186	1.251	0.236	0.085	0.414	0.113	0.035	0.003
Norway	0.264	0.117	0.013	0.005	0.039	0.017	0.005	0.000
Switzerland	0.321	0.043	0.016	0.004	0.187	0.022	0.008	0.002

Table 98 - Total inter-urban congestion costs generated on motorway network, estimated using the simplified approach (billion Euro/year, in Euro$_{2016}$)

Country	Deadweight loss				Delay cost			
	Car	LCVs	Trucks (HGV)	Coaches	Car	LCVs	Trucks (HGV)	Coaches
EU28	0.724	0.196	0.085	0.015	3.182	0.861	0.375	0.066
Austria	0.014	0.005	0.001	0.000	0.063	0.022	0.005	0.001
Belgium	0.069	0.014	0.006	0.001	0.299	0.060	0.024	0.004
Bulgaria	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Croatia	0.001	0.000	0.000	0.000	0.004	0.001	0.000	0.000
Cyprus	-	-	-	-	-	-	-	-
Czech Republic	0.004	0.001	0.001	0.000	0.018	0.005	0.003	0.001
Denmark	0.011	0.003	0.001	0.000	0.048	0.015	0.004	0.001
Estonia	-	-	-	-	-	-	-	-
Finland	0.004	0.001	0.000	0.000	0.019	0.003	0.001	0.000
France	0.192	0.073	0.013	0.003	0.848	0.321	0.057	0.014
Germany	0.119	0.010	0.010	0.001	0.526	0.044	0.044	0.004
Greece	0.010	0.005	0.001	0.001	0.044	0.023	0.005	0.004
Hungary	0.010	0.003	0.003	0.001	0.045	0.014	0.012	0.005
Ireland	0.013	0.009	0.002	0.000	0.056	0.037	0.008	0.002
Italy	0.077	0.016	0.007	0.003	0.337	0.071	0.031	0.015
Latvia	-	-	-	-	-	-	-	-
Lithuania	0.003	0.000	0.001	0.000	0.011	0.002	0.006	0.000
Luxembourg	0.010	0.013	0.004	0.000	0.045	0.056	0.016	0.001
Malta	-	-	-	-	-	-	-	-
Netherlands	0.054	0.011	0.007	0.000	0.231	0.047	0.032	0.001
Poland	0.007	0.001	0.003	0.000	0.032	0.005	0.014	0.000
Portugal	0.021	0.009	0.004	0.000	0.091	0.038	0.018	0.002
Romania	0.002	0.001	0.001	0.000	0.008	0.004	0.003	0.001
Slovakia	0.001	0.000	0.000	0.000	0.006	0.002	0.002	0.000
Slovenia	0.005	0.001	0.001	0.000	0.020	0.005	0.003	0.000
Spain	0.049	0.007	0.015	0.002	0.220	0.031	0.067	0.010
Sweden	0.011	0.003	0.001	0.000	0.050	0.012	0.003	0.001
United Kingdom	0.037	0.010	0.004	0.000	0.158	0.041	0.016	0.001
Norway	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Switzerland	0.045	0.006	0.003	0.001	0.190	0.024	0.011	0.002

F.4 Detailed estimated congestion costs by country - Total costs borne by mode

Table 99 - Total car congestion costs (billion Euro/year, in Euro$_{2016}$)

Country	Deadweight loss	Delay cost	Deadweight loss	Delay cost	Deadweight loss	Delay cost
	Total (urban and inter-urban)		Urban		Inter-urban	
EU28	35.553	206.158	30.006	172.574	5.547	33.584
Austria	0.475	2.671	0.371	2.059	0.104	0.612
Belgium	1.186	7.268	0.762	4.854	0.423	2.414
Bulgaria	0.245	1.438	0.237	1.361	0.008	0.077
Croatia	0.164	0.939	0.155	0.875	0.009	0.064
Cyprus	0.057	0.322	0.057	0.322	-	-
Czech Republic	0.492	2.855	0.453	2.540	0.038	0.314
Denmark	0.395	2.144	0.262	1.490	0.133	0.655
Estonia	0.049	0.294	0.043	0.238	0.006	0.055
Finland	0.348	1.938	0.327	1.832	0.021	0.106
France	4.616	25.863	3.078	17.417	1.538	8.446
Germany	6.230	35.624	5.555	31.339	0.675	4.285
Greece	0.721	3.921	0.630	3.499	0.091	0.422
Hungary	0.318	1.880	0.280	1.592	0.038	0.288
Ireland	0.769	6.074	0.648	5.022	0.121	1.052
Italy	4.228	23.633	3.549	19.831	0.680	3.803
Latvia	0.080	0.467	0.078	0.443	0.003	0.024
Lithuania	0.131	0.764	0.126	0.722	0.005	0.042
Luxembourg	0.130	0.773	0.079	0.464	0.051	0.309
Malta	0.010	0.063	0.010	0.063	-	-
Netherlands	1.458	8.276	1.223	6.969	0.235	1.307
Poland	1.624	10.023	1.353	7.650	0.271	2.373
Portugal	0.861	4.934	0.718	4.043	0.142	0.891
Romania	0.812	5.784	0.755	5.189	0.057	0.594
Slovakia	0.154	0.946	0.128	0.736	0.026	0.210
Slovenia	0.061	0.357	0.044	0.255	0.018	0.102
Spain	3.001	16.716	2.631	14.530	0.370	2.187
Sweden	0.927	5.231	0.883	5.007	0.043	0.224
United Kingdom	6.012	34.960	5.572	32.232	0.440	2.728
Norway	0.311	1.745	0.271	1.555	0.040	0.190
Switzerland	0.524	2.972	0.338	1.979	0.186	0.993
*Canada**	0.965	4.965	0.965	4.965	-	-
*US**	10.906	63.873	10.906	63.873	-	-
*Japan**	4.715	22.022	4.715	22.022	-	-

* Canada: Estimations for Alberta and British Columbia.

* USA: Estimations for California and Missouri.

* Japan: Estimations for cities above 500,000 inhabitants.

Table 100 - Total trucks, coaches and LCVs inter-urban congestion costs (billion Euro/year, in Euro2016)

Country	Deadweight loss			Delay cost		
	Trucks (HGV)	Coaches	LCVs*	Trucks (HGV)	Coaches	LCVs*
EU28	0.696	0.218	1.031	6.234	2.112	5.930
Austria	0.014	0.005	0.018	0.108	0.055	0.103
Belgium	0.056	0.030	0.068	0.470	0.086	0.388
Bulgaria	0.001	0.001	0.000	0.007	0.008	0.002
Croatia	0.001	0.000	0.001	0.008	0.003	0.008
Cyprus	-	-	-	-	-	-
Czech Republic	0.003	0.006	0.003	0.028	0.039	0.023
Denmark	0.009	0.004	0.034	0.071	0.028	0.169
Estonia	0.000	0.000	0.000	0.000	0.004	0.002
Finland	0.006	0.000	0.002	0.048	0.005	0.011
France	0.176	0.030	0.534	1.956	0.538	2.939
Germany	0.106	0.017	0.028	0.910	0.188	0.177
Greece	0.004	0.010	0.009	0.027	0.064	0.040
Hungary	0.008	0.006	0.004	0.058	0.068	0.034
Ireland	0.011	0.009	0.023	0.113	0.074	0.189
Italy	0.058	0.030	0.129	0.395	0.369	0.726
Latvia	0.001	0.000	0.000	0.006	0.001	0.002
Lithuania	0.001	0.000	0.000	0.003	0.000	0.002
Luxembourg	0.005	0.004	0.026	0.028	0.015	0.154
Malta	-	-	-	-	-	-
Netherlands	0.022	0.010	0.027	0.153	0.014	0.149
Poland	0.051	0.011	0.019	0.460	0.114	0.166
Portugal	0.017	0.006	0.012	0.145	0.039	0.067
Romania	0.005	0.003	0.003	0.048	0.062	0.032
Slovakia	0.003	0.002	0.002	0.026	0.011	0.017
Slovenia	0.001	0.001	0.002	0.004	0.009	0.011
Spain	0.086	0.023	0.011	0.741	0.241	0.060
Sweden	0.008	0.001	0.007	0.060	0.011	0.034
United Kingdom	0.047	0.010	0.068	0.362	0.065	0.423
Norway	0.007	0.001	0.013	0.070	0.008	0.061
Switzerland	0.016	0.005	0.012	0.169	0.020	0.065

* Estimated with a simplified approach based on estimated value of congestion costs for passenger cars.

Table 101 - Total trucks urban congestion costs (billion Euro/year, in Euro2016)

Country	Deadweight loss		Delay cost	
	HGVs	LCVs*	HGVs	LCVs*
EU28	3.090	5.614	17.609	32.562
Austria	0.045	0.090	0.251	0.498
Belgium	0.039	0.127	0.246	0.808
Bulgaria	0.026	0.007	0.148	0.038
Croatia	0.013	0.025	0.075	0.143
Cyprus	0.002	0.013	0.011	0.074
Czech Republic	0.065	0.038	0.363	0.212
Denmark	0.028	0.067	0.161	0.383
Estonia	0.005	0.002	0.027	0.012

Country	Deadweight loss		Delay cost	
	HGVs	LCVs*	HGVs	LCVs*
Finland	0.026	0.036	0.146	0.203
France	0.208	0.936	1.179	5.293
Germany	0.788	0.517	4.444	2.917
Greece	0.046	0.060	0.258	0.335
Hungary	0.060	0.043	0.343	0.244
Ireland	0.009	0.327	0.068	2.532
Italy	0.242	0.933	1.353	5.215
Latvia	0.018	0.005	0.105	0.031
Lithuania	0.022	0.012	0.128	0.070
Luxembourg	0.014	0.037	0.082	0.218
Malta	0.004	0.001	0.025	0.007
Netherlands	0.093	0.372	0.532	2.121
Poland	0.467	0.107	2.640	0.606
Portugal	0.045	0.370	0.256	2.082
Romania	0.080	0.043	0.547	0.294
Slovakia	0.031	0.012	0.179	0.067
Slovenia	0.012	0.006	0.067	0.037
Spain	0.267	0.453	1.476	2.500
Sweden	0.078	0.143	0.440	0.809
United Kingdom	0.356	0.832	2.059	4.812
Norway	0.032	0.096	0.184	0.549
Switzerland	0.017	0.028	0.102	0.163

* Estimated with a simplified approach based on estimated value of congestion costs for passenger cars.

Table 102 - Total inter-urban congestion costs on motorway network (billion Euro/year, in Euro$_{2016}$)

Country	Deadweight loss				Delay cost			
	Car	Trucks (HGV)	Coaches	LCVs*	Car	Trucks (HGV)	Coaches	LCVs*
EU28	0.670	0.194	0.034	0.122	2.913	1.086	0.203	0.498
Austria	0.013	0.005	0.001	0.002	0.051	0.026	0.005	0.009
Belgium	0.060	0.017	0.002	0.010	0.244	0.094	0.010	0.040
Bulgaria	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
Croatia	0.001	0.000	0.000	0.000	0.004	0.001	0.000	0.001
Cyprus	-	-	-	-	-	-	-	-
Czech Republic	0.005	0.000	0.000	0.000	0.020	0.002	0.003	0.001
Denmark	0.011	0.002	0.000	0.002	0.046	0.010	0.002	0.009
Estonia	-	-	-	-	-	-	-	-
Finland	0.003	0.001	0.000	0.000	0.014	0.007	0.001	0.001
France	0.162	0.058	0.009	0.052	0.658	0.318	0.050	0.214
Germany	0.104	0.027	0.004	0.005	0.424	0.151	0.022	0.021
Greece	0.012	0.001	0.001	0.002	0.049	0.007	0.009	0.010
Hungary	0.009	0.005	0.002	0.001	0.037	0.025	0.010	0.004
Ireland	0.015	0.003	0.001	0.004	0.062	0.018	0.005	0.018
Italy	0.072	0.014	0.006	0.012	0.295	0.077	0.034	0.048
Latvia	-	-	-	-	-	-	-	-
Lithuania	0.004	0.000	0.000	0.000	0.015	0.002	0.000	0.001
Luxembourg	0.015	0.004	0.001	0.008	0.062	0.020	0.003	0.032
Malta	-	-	-	-	-	-	-	-

Country	Deadweight loss				Delay cost			
	Car	Trucks (HGV)	Coaches	LCVs*	Car	Trucks (HGV)	Coaches	LCVs*
Netherlands	0.052	0.014	0.000	0.006	0.211	0.075	0.003	0.022
Poland	0.008	0.003	0.000	0.000	0.032	0.016	0.002	0.002
Portugal	0.025	0.004	0.001	0.005	0.102	0.023	0.005	0.019
Romania	0.002	0.000	0.000	0.000	0.010	0.002	0.001	0.001
Slovakia	0.002	0.000	0.000	0.000	0.008	0.001	0.000	0.001
Slovenia	0.005	0.000	0.000	0.001	0.023	0.002	0.002	0.003
Spain	0.042	0.024	0.004	0.003	0.165	0.127	0.022	0.014
Sweden	0.009	0.004	0.000	0.001	0.038	0.021	0.002	0.006
United Kingdom	0.037	0.007	0.001	0.005	0.150	0.041	0.004	0.022
Norway	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Switzerland	0.046	0.003	0.001	0.003	0.190	0.019	0.004	0.014

* Estimated with a simplified approach based on estimated value of congestion costs for passenger cars.

F.5 Detailed estimated congestion costs by country - Costs per vkm borne on congested roads

Table 103 - Car deadweight loss per vkm on congested network (€-cent/vkm, in $Euro_{2016}$)

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
EU28	3.76	2.61	1.47	7.65	6.54	4.72	3.66	2.54	1.45	5.73	4.67	3.21
Austria	4.18	2.90	1.64	8.49	7.26	5.24	4.06	2.82	1.61	6.36	5.19	3.56
Belgium	4.35	3.01	1.70	8.84	7.55	5.45	4.26	2.96	1.68	6.67	5.44	3.73
Bulgaria	2.41	1.67	0.94	4.90	4.19	3.02	2.31	1.61	0.91	3.62	2.95	2.03
Croatia	2.90	2.01	1.14	5.90	5.04	3.64	2.78	1.93	1.10	4.35	3.55	2.44
Cyprus	3.11	2.16	1.22	6.32	5.41	3.90	2.98	2.07	1.18	4.67	3.81	2.61
Czech Republic	4.13	2.86	1.62	8.39	7.17	5.17	4.03	2.80	1.59	6.31	5.15	3.53
Denmark	3.90	2.70	1.52	7.92	6.77	4.88	3.74	2.60	1.48	5.86	4.78	3.28
Estonia	3.24	2.24	1.27	6.58	5.63	4.06	3.19	2.22	1.26	5.00	4.08	2.80
Finland	3.74	2.59	1.46	7.61	6.50	4.69	3.64	2.53	1.44	5.70	4.65	3.19
France	3.58	2.48	1.40	7.28	6.22	4.49	3.45	2.40	1.36	5.40	4.41	3.02
Germany	3.77	2.61	1.47	7.66	6.55	4.72	3.68	2.56	1.46	5.77	4.70	3.23
Greece	2.99	2.07	1.17	6.08	5.20	3.75	2.94	2.04	1.16	4.61	3.76	2.58
Hungary	3.26	2.26	1.28	6.63	5.67	4.09	3.09	2.15	1.22	4.84	3.95	2.71
Ireland	7.39	5.12	2.89	15.01	12.83	9.26	7.51	5.22	2.97	11.77	9.60	6.59
Italy	3.59	2.48	1.40	7.29	6.23	4.49	3.47	2.41	1.37	5.44	4.43	3.04
Latvia	3.29	2.28	1.29	6.69	5.72	4.13	3.09	2.15	1.22	4.84	3.95	2.71
Lithuania	3.58	2.48	1.40	7.27	6.22	4.49	3.36	2.33	1.33	5.26	4.29	2.94
Luxembourg	8.21	5.69	3.21	16.68	14.26	10.29	7.93	5.51	3.13	12.42	10.13	6.95
Malta	3.41	2.36	1.33	6.92	5.92	4.27	3.26	2.27	1.29	5.11	4.17	2.86
Netherlands	4.47	3.10	1.75	9.08	7.76	5.60	4.24	2.95	1.68	6.65	5.42	3.72
Poland	3.34	2.31	1.31	6.79	5.80	4.18	3.28	2.28	1.30	5.13	4.19	2.87
Portugal	3.28	2.27	1.28	6.66	5.69	4.11	3.16	2.20	1.25	4.95	4.04	2.77
Romania	2.99	2.07	1.17	6.08	5.20	3.75	3.44	2.39	1.36	5.39	4.39	3.01

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
Slovakia	4.09	2.83	1.60	8.31	7.11	5.13	3.89	2.71	1.54	6.10	4.98	3.41
Slovenia	3.16	2.19	1.24	6.43	5.50	3.97	3.02	2.10	1.19	4.73	3.86	2.65
Spain	3.66	2.54	1.43	7.44	6.36	4.59	3.59	2.50	1.42	5.63	4.59	3.15
Sweden	4.08	2.82	1.60	8.29	7.08	5.11	3.98	2.76	1.57	6.23	5.08	3.49
United Kingdom	3.66	2.54	1.43	7.44	6.36	4.59	3.58	2.49	1.41	5.61	4.57	3.14
Norway	4.93	3.42	1.93	10.02	8.57	6.18	4.43	3.08	1.75	6.94	5.66	3.88
Switzerland	5.04	3.49	1.97	10.24	8.76	6.32	4.80	3.34	1.90	7.53	6.14	4.21
Canada[73]	2.83	1.96	1.11	5.76	4.92	3.55						
United States[74]	4.88	3.38	1.91	9.91	8.47	6.11						
Japan[75]	4.57	3.16	1.79	9.28	7.93	5.72						

Over capacity: flow to capacity ratio above 1.2.

Congested: flow to capacity ratio between 1.0 and 1.2.

Near capacity: flow to capacity ratio between 0.8 and 1.0.

73 Estimations for Alberta and British Columbia.

74 Estimations for California and Missouri.

75 Estimations based on the city of Tokyo.

Table 104 - Inter-urban deadweight loss per vkm borne on congested network for trucks and coaches (€-cent/vkm, in Euro$_{2016}$)

Country	Trucks						Coaches					
	Motorways			Other road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
EU28	10.87	7.50	4.17	13.52	11.05	7.51	28.36	19.57	10.89	35.30	28.83	19.60
Austria	13.93	9.61	5.35	17.33	14.16	9.62	35.13	24.23	13.48	43.71	35.70	24.27
Belgium	12.55	8.66	4.82	15.61	12.75	8.67	32.39	22.34	12.43	40.30	32.92	22.38
Bulgaria	5.20	3.58	1.99	6.47	5.28	3.59	13.41	9.25	5.15	16.69	13.63	9.26
Croatia	5.87	4.05	2.25	7.30	5.96	4.05	16.52	11.40	6.34	20.56	16.80	11.42
Cyprus	7.28	5.02	2.79	9.06	7.40	5.03	22.85	15.76	8.77	28.44	23.23	15.79
Czech Republic	7.50	5.18	2.88	9.34	7.63	5.18	24.17	16.68	9.28	30.08	24.57	16.70
Denmark	11.56	7.98	4.44	14.39	11.75	7.99	34.09	23.51	13.09	42.42	34.65	23.55
Estonia	7.77	5.36	2.98	9.67	7.90	5.37	20.68	14.27	7.94	25.73	21.02	14.29
Finland	18.27	12.61	7.02	22.74	18.57	12.63	30.12	20.78	11.56	37.48	30.62	20.81
France	13.99	9.65	5.37	17.40	14.21	9.66	28.70	19.80	11.02	35.72	29.18	19.83
Germany	12.22	8.43	4.69	15.20	12.42	8.44	33.99	23.45	13.05	42.30	34.55	23.49
Greece	10.80	7.45	4.15	13.44	10.98	7.46	18.60	12.83	7.14	23.15	18.91	12.85
Hungary	7.82	5.39	3.00	9.73	7.94	5.40	18.60	12.83	7.14	23.15	18.91	12.85
Ireland	13.37	9.22	5.13	16.63	13.58	9.23	50.33	34.72	19.32	62.63	51.15	34.77
Italy	10.42	7.19	4.00	12.97	10.60	7.20	26.63	18.37	10.22	33.14	27.06	18.40
Latvia	7.58	5.23	2.91	9.43	7.70	5.23	17.75	12.25	6.81	22.09	18.04	12.26
Lithuania	6.04	4.17	2.32	7.52	6.14	4.17	20.77	14.33	7.97	25.85	21.11	14.35
Luxembourg	18.98	13.09	7.28	23.61	19.29	13.11	70.91	48.92	27.22	88.24	72.08	48.99
Malta	8.19	5.65	3.14	10.19	8.32	5.66	25.97	17.91	9.97	32.31	26.39	17.94
Netherlands	11.57	7.98	4.44	14.40	11.76	7.99	35.13	24.23	13.48	43.71	35.70	24.27
Poland	8.02	5.53	3.08	9.98	8.15	5.54	18.79	12.96	7.21	23.38	19.10	12.98
Portugal	10.55	7.28	4.05	13.13	10.72	7.29	21.34	14.72	8.19	26.56	21.69	14.74
Romania	5.46	3.77	2.10	6.79	5.55	3.77	16.05	11.07	6.16	19.98	16.32	11.09
Slovakia	7.84	5.41	3.01	9.76	7.97	5.42	21.15	14.59	8.12	26.32	21.50	14.61
Slovenia	11.05	7.62	4.24	13.75	11.23	7.63	22.76	15.70	8.74	28.32	23.13	15.72
Spain	12.57	8.67	4.83	15.64	12.78	8.68	25.21	17.39	9.68	31.37	25.62	17.42

Country	Trucks						Coaches					
	Motorways			Other road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
Sweden	16.33	11.27	6.27	20.32	16.60	11.28	33.99	23.45	13.05	42.30	34.55	23.49
United Kingdom	10.28	7.09	3.95	12.79	10.45	7.10	29.65	20.45	11.38	36.90	30.14	20.48
Norway	22.52	15.53	8.64	28.02	22.89	15.56	40.89	28.20	15.70	50.88	41.56	28.25
Switzerland	10.51	7.25	4.03	13.08	10.68	7.26	44.38	30.61	17.04	55.23	45.11	30.66

Over capacity: flow to capacity ratio above 1.2.

Congested: flow to capacity ratio between 1.0 and 1.2.

Near capacity: flow to capacity ratio between 0.8 and 1.0.

Table 105 - Car delay costs per vkm borne on congested network (€-cent/vkm, in Euro$_{2016}$)

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
EU28	25.7	12.4	5.1	73.4	38.8	17.8	23.5	11.3	4.6	47.7	24.7	11.1
Austria	28.5	13.7	5.6	81.6	43.1	19.7	26.1	12.6	5.2	53.0	27.5	12.3
Belgium	29.7	14.3	5.9	84.9	44.8	20.5	27.3	13.2	5.4	55.5	28.8	12.9
Bulgaria	16.5	7.9	3.2	47.1	24.9	11.4	14.8	7.2	2.9	30.1	15.6	7.0
Croatia	19.8	9.6	3.9	56.7	29.9	13.7	17.8	8.6	3.5	36.2	18.8	8.4
Cyprus	21.2	10.2	4.2	60.7	32.1	14.7	19.1	9.2	3.8	38.8	20.1	9.0
Czech Republic	28.2	13.6	5.6	80.6	42.6	19.5	25.9	12.5	5.1	52.5	27.3	12.2
Denmark	26.6	12.8	5.2	76.0	40.2	18.4	24.0	11.6	4.7	48.7	25.3	11.3
Estonia	22.1	10.7	4.4	63.2	33.4	15.3	20.5	9.9	4.0	41.6	21.6	9.7
Finland	25.5	12.3	5.0	73.0	38.6	17.7	23.3	11.3	4.6	47.4	24.6	11.0
France	24.4	11.8	4.8	69.9	36.9	16.9	22.1	10.7	4.4	45.0	23.3	10.4
Germany	25.7	12.4	5.1	73.6	38.9	17.8	23.6	11.4	4.7	48.0	24.9	11.1
Greece	20.4	9.8	4.0	58.4	30.9	14.1	18.9	9.1	3.7	38.4	19.9	8.9
Hungary	22.2	10.7	4.4	63.6	33.6	15.4	19.9	9.6	3.9	40.3	20.9	9.4
Ireland	50.4	24.3	10.0	144.1	76.1	34.9	48.2	23.3	9.5	98.0	50.8	22.8

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
Italy	24.5	11.8	4.8	70.0	37.0	16.9	22.3	10.7	4.4	45.2	23.5	10.5
Latvia	22.5	10.8	4.4	64.3	34.0	15.5	19.8	9.6	3.9	40.3	20.9	9.4
Lithuania	24.4	11.8	4.8	69.8	36.9	16.9	21.6	10.4	4.3	43.8	22.7	10.2
Luxembourg	56.0	27.0	11.1	160.2	84.6	38.8	50.9	24.5	10.1	103.4	53.6	24.0
Malta	23.2	11.2	4.6	66.5	35.1	16.1	20.9	10.1	4.1	42.5	22.0	9.9
Netherlands	30.5	14.7	6.0	87.2	46.1	21.1	27.2	13.1	5.4	55.3	28.7	12.9
Poland	22.8	11.0	4.5	65.2	34.4	15.8	21.0	10.1	4.2	42.7	22.2	9.9
Portugal	22.3	10.8	4.4	63.9	33.8	15.5	20.3	9.8	4.0	41.2	21.4	9.6
Romania	20.4	9.8	4.0	58.4	30.8	14.1	22.1	10.6	4.4	44.8	23.3	10.4
Slovakia	27.9	13.5	5.5	79.8	42.2	19.3	25.0	12.1	4.9	50.8	26.3	11.8
Slovenia	21.6	10.4	4.3	61.8	32.6	14.9	19.4	9.3	3.8	39.3	20.4	9.1
Spain	25.0	12.0	4.9	71.4	37.7	17.3	23.1	11.1	4.6	46.9	24.3	10.9
Sweden	27.8	13.4	5.5	79.6	42.0	19.3	25.5	12.3	5.0	51.9	26.9	12.1
United Kingdom	25.0	12.1	4.9	71.5	37.8	17.3	23.0	11.1	4.5	46.7	24.2	10.8
Norway	33.6	16.2	6.6	96.3	50.9	23.3	28.4	13.7	5.6	57.7	29.9	13.4
Switzerland	34.4	16.6	6.8	98.4	52.0	23.8	30.9	14.9	6.1	62.7	32.5	14.6
Canada[76]	19.3	9.3	3.8	55.2	29.2	13.4						
United States[77]	33.2	16.0	6.6	95.1	50.2	23.0						
Japan[78]	31.1	15.0	6.1	89.0	47.0	21.5						

Over capacity: flow to capacity ratio above 1.2.

Congested: flow to capacity ratio between 1.0 and 1.2.

Near capacity: flow to capacity ratio between 0.8 and 1.0.

[76] Estimations for Alberta and British Columbia.

[77] Estimations for California and Missouri.

[78] Estimations based on the city of Tokyo.

Table 106 - Inter-urban delay congestion costs per vkm borne on congested network for trucks and coaches (Euro Cent/vkm, in Euro$_{2016}$)

Country	Trucks						Coaches					
	Motorways			Other road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
EU28	97.6	47.1	19.3	163.9	85.0	38.1	254.8	122.9	50.3	427.7	221.9	99.4
Austria	125.1	60.3	24.7	210.0	108.9	48.8	315.5	152.2	62.3	529.6	274.7	123.0
Belgium	112.7	54.4	22.3	189.2	98.1	43.9	290.9	140.3	57.5	488.3	253.3	113.4
Bulgaria	46.7	22.5	9.2	78.4	40.6	18.2	120.4	58.1	23.8	202.2	104.9	47.0
Croatia	52.7	25.4	10.4	88.5	45.9	20.6	148.4	71.6	29.3	249.2	129.2	57.9
Cyprus	65.4	31.5	12.9	109.8	56.9	25.5	205.3	99.0	40.5	344.5	178.7	80.0
Czech Republic	67.4	32.5	13.3	113.1	58.7	26.3	217.1	104.7	42.9	364.5	189.1	84.7
Denmark	103.9	50.1	20.5	174.3	90.4	40.5	306.2	147.7	60.5	514.0	266.6	119.4
Estonia	69.8	33.7	13.8	117.1	60.8	27.2	185.8	89.6	36.7	311.8	161.7	72.4
Finland	164.1	79.2	32.4	275.5	142.9	64.0	270.6	130.5	53.4	454.2	235.6	105.5
France	125.6	60.6	24.8	210.9	109.4	49.0	257.8	124.3	50.9	432.8	224.5	100.5
Germany	109.7	52.9	21.7	184.2	95.6	42.8	305.3	147.3	60.3	512.5	265.9	119.1
Greece	97.0	46.8	19.2	162.9	84.5	37.8	167.1	80.6	33.0	280.5	145.5	65.2
Hungary	70.2	33.9	13.9	117.8	61.1	27.4	167.1	80.6	33.0	280.5	145.5	65.2
Ireland	120.1	57.9	23.7	201.5	104.5	46.8	452.1	218.0	89.3	758.9	393.6	176.3
Italy	93.6	45.2	18.5	157.2	81.5	36.5	239.2	115.3	47.2	401.5	208.3	93.3
Latvia	68.1	32.8	13.4	114.2	59.3	26.5	159.5	76.9	31.5	267.7	138.8	62.2
Lithuania	54.3	26.2	10.7	91.1	47.3	21.2	186.6	90.0	36.9	313.2	162.5	72.8
Luxembourg	170.5	82.2	33.7	286.1	148.4	66.5	637.0	307.2	125.8	1069.2	554.6	248.4
Malta	73.5	35.5	14.5	123.4	64.0	28.7	233.3	112.5	46.1	391.5	203.1	91.0
Netherlands	103.9	50.1	20.5	174.4	90.5	40.5	315.5	152.2	62.3	529.6	274.7	123.0
Poland	72.1	34.7	14.2	120.9	62.7	28.1	168.8	81.4	33.3	283.3	147.0	65.8
Portugal	94.8	45.7	18.7	159.1	82.5	36.9	191.7	92.4	37.9	321.8	166.9	74.7
Romania	49.0	23.6	9.7	82.3	42.7	19.1	144.2	69.5	28.5	242.0	125.6	56.2
Slovakia	70.4	34.0	13.9	118.2	61.3	27.5	190.0	91.6	37.5	318.9	165.4	74.1
Slovenia	99.2	47.9	19.6	166.6	86.4	38.7	204.4	98.6	40.4	343.1	178.0	79.7
Spain	112.9	54.4	22.3	189.5	98.3	44.0	226.5	109.2	44.7	380.1	197.2	88.3

Country	Trucks						Coaches					
	Motorways			Other road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
Sweden	146.7	70.8	29.0	246.3	127.7	57.2	305.3	147.3	60.3	512.5	265.9	119.1
United Kingdom	92.3	44.5	18.2	155.0	80.4	36.0	266.3	128.4	52.6	447.1	231.9	103.9
Norway	202.3	97.5	40.0	339.5	176.1	78.9	367.3	177.1	72.5	616.5	319.8	143.2
Switzerland	94.4	45.5	18.6	158.4	82.2	36.8	398.6	192.2	78.7	669.2	347.1	155.5

Over capacity: flow to capacity ratio above 1.2.

Congested: flow to capacity ratio between 1.0 and 1.2.

Near capacity: flow to capacity ratio between 0.8 and 1.0.

F.6 Detailed estimated congestion costs by country - Average costs on the whole network

Table 107 - Car average[79] delay congestion cost and deadweight loss generated per vkm, estimated using the simplified approach (€-cent/vkm, in Euro$_{2016}$)

Country	Deadweight loss	Delay cost	Deadweight loss	Delay cost	Deadweight loss	Delay cost
	Total (urban and inter-urban)		Urban		Inter-urban	
EU28	1.14	6.69	3.09	17.73	0.27	1.74
Austria	1.10	6.45	3.05	17.47	0.29	1.83
Belgium	0.90	5.12	2.38	13.23	0.28	1.78
Bulgaria	1.50	9.26	3.86	24.55	0.76	4.43
Croatia	0.65	3.81	1.42	8.16	0.04	0.39
Cyprus	0.74	4.26	2.39	13.54	0.06	0.44
Czech Republic	1.20	6.78	2.72	15.41	0.00	0.00
Denmark	0.94	5.47	2.18	12.20	0.13	1.01
Estonia	1.02	5.62	1.96	11.10	0.52	2.67
Finland	0.54	3.23	1.35	7.52	0.10	0.91
France	0.71	4.01	1.90	10.64	0.08	0.44
Germany	1.04	6.02	2.27	12.83	0.50	3.06
Greece	1.07	6.15	3.50	19.74	0.17	1.13
Hungary	1.08	5.92	2.15	11.91	0.25	1.21
Ireland	1.00	5.96	2.40	13.64	0.20	1.60
Italy	1.59	12.67	4.26	33.02	0.45	3.95
Latvia	0.96	5.42	3.90	21.78	0.20	1.19
Lithuania	0.89	5.19	2.47	14.04	0.05	0.43
Luxembourg	0.71	4.14	1.81	10.37	0.04	0.32
Malta	1.90	11.28	4.85	28.56	0.97	5.83
Netherlands	0.64	3.98	1.28	7.96	0.00	0.00
Poland	1.23	6.97	4.75	27.06	0.27	1.49
Portugal	1.28	7.88	2.78	15.73	0.32	2.82
Romania	1.35	7.87	3.10	17.46	0.41	2.70
Slovakia	1.77	12.69	3.73	25.67	0.23	2.48
Slovenia	0.75	4.61	1.60	9.20	0.20	1.57
Spain	0.35	2.08	0.90	5.23	0.13	0.79
Sweden	1.44	8.22	3.52	19.42	0.33	2.19
United Kingdom	1.34	7.57	3.63	20.58	0.10	0.57
Norway	1.40	8.18	3.27	18.94	0.17	1.09
Switzerland	0.88	5.01	2.19	12.58	0.17	0.94

79 Based on the whole network (not only congested network).

Table 108 – Bus/coaches average[80] delay congestion cost and deadweight loss generated per vkm, estimated using the simplified approach (€-cent/vkm, in Euro$_{2016}$)

Country	Deadweight loss	Delay cost	Deadweight loss	Delay cost	Deadweight loss	Delay cost
	Total (urban and inter-urban)		Urban		Inter-urban	
EU28	2.69	15.89	6.09	35.52	0.48	3.09
Austria	2.57	15.20	6.02	35.20	0.48	3.13
Belgium	1.74	9.94	4.76	26.47	0.54	3.36
Bulgaria	4.42	27.68	7.71	49.11	1.61	9.42
Croatia	1.48	8.62	2.84	16.33	0.05	0.51
Cyprus	1.45	8.30	4.78	27.07	0.12	0.82
Czech Republic	3.05	17.29	5.44	30.83	0.00	0.00
Denmark	1.69	9.94	4.35	24.41	0.26	2.14
Estonia	2.34	12.94	3.91	22.20	1.10	5.69
Finland	1.07	6.45	2.70	15.04	0.20	1.83
France	2.21	12.37	3.80	21.27	0.15	0.88
Germany	2.40	13.80	4.53	25.65	0.97	5.84
Greece	2.45	14.20	7.00	39.48	0.40	2.76
Hungary	1.81	9.89	4.29	23.83	0.40	1.91
Ireland	1.89	11.21	4.79	27.29	0.42	3.06
Italy	5.45	42.36	8.52	66.03	0.74	6.01
Latvia	2.50	13.97	7.80	43.57	0.28	1.57
Lithuania	1.79	10.39	4.94	28.09	0.09	0.86
Luxembourg	2.04	11.69	3.62	20.75	0.09	0.62
Malta	5.53	32.83	9.69	57.11	1.99	12.14
Netherlands	1.28	7.96	2.55	15.92	0.00	0.00
Poland	3.92	22.25	9.50	54.13	0.50	2.71
Portugal	3.11	18.64	5.56	31.45	0.64	5.75
Romania	2.80	15.78	6.20	34.92	0.48	2.77
Slovakia	4.23	29.56	7.47	51.34	0.31	3.24
Slovenia	1.76	10.70	3.19	18.41	0.45	3.66
Spain	0.69	4.07	1.80	10.47	0.25	1.52
Sweden	2.22	12.40	7.03	38.84	0.36	2.16
United Kingdom	3.97	22.52	7.26	41.16	0.20	1.14
Norway	4.19	24.32	6.55	37.89	0.37	2.34
Switzerland	2.50	14.30	4.38	25.15	0.35	1.91

80 Based on the whole network (not only congested network).

Table 109 – Freight HGV average[81] delay congestion cost and deadweight loss generated per vkm, estimated using the simplified approach (€-cent/vkm, in Euro$_{2016}$)

Country	Deadweight loss	Delay cost	Deadweight loss	Delay cost	Deadweight loss	Delay cost
	Total (urban and inter-urban)		Urban		Inter-urban	
EU28	1.84	10.85	5.96	34.10	0.45	3.02
Austria	1.83	10.81	5.89	33.65	0.46	3.13
Belgium	1.77	10.06	4.76	26.47	0.49	3.04
Bulgaria	2.28	13.75	7.71	49.11	1.32	7.51
Croatia	1.03	6.09	2.84	16.33	0.06	0.58
Cyprus	1.51	8.64	4.78	27.07	0.11	0.74
Czech Republic	1.90	10.79	5.44	30.83	0.00	0.00
Denmark	1.73	10.13	4.35	24.41	0.26	2.10
Estonia	1.95	10.67	3.91	22.20	1.03	5.25
Finland	0.97	5.83	2.70	15.04	0.16	1.49
France	0.89	5.00	3.80	21.27	0.16	0.93
Germany	1.74	10.09	4.53	25.65	0.93	5.55
Greece	2.26	13.00	7.00	39.48	0.33	2.18
Hungary	1.77	9.66	4.29	23.83	0.42	2.03
Ireland	1.73	10.43	4.79	27.29	0.41	3.14
Italy	1.41	10.68	8.52	66.03	0.62	4.53
Latvia	1.48	8.33	7.80	43.57	0.36	2.11
Lithuania	1.63	9.46	4.94	28.09	0.08	0.70
Luxembourg	0.94	5.45	3.62	20.75	0.09	0.62
Malta	3.01	17.50	9.69	57.11	1.84	10.51
Netherlands	1.28	7.96	2.55	15.92	0.00	0.00
Poland	1.55	8.70	9.50	54.13	0.47	2.51
Portugal	2.31	14.39	5.56	31.45	0.64	5.60
Romania	1.35	7.68	6.20	34.92	0.47	2.74
Slovakia	2.84	20.34	7.47	51.34	0.34	3.64
Slovenia	1.41	8.73	3.19	18.41	0.41	3.29
Spain	0.71	4.13	1.80	10.47	0.24	1.42
Sweden	1.38	7.77	7.03	38.84	0.35	2.13
United Kingdom	1.61	9.15	7.26	41.16	0.20	1.15
Norway	1.92	11.21	6.55	37.89	0.33	2.07
Switzerland	1.19	6.73	4.38	25.15	0.39	2.13

81 Based on the whole network (not only congested network).

Table 110 - Light commercial vehicle average[82] delay congestion cost and deadweight loss generated per vkm, estimated using the simplified approach (€-cent/vkm, in $Euro_{2016}$)

Country	Deadweight loss	Delay cost	Deadweight loss	Delay cost	Deadweight loss	Delay cost
	Total (urban and inter-urban)		Urban		Inter-urban	
EU28	1.97	11.61	4.71	27.42	0.47	2.92
Austria	1.97	11.62	4.68	27.24	0.50	3.13
Belgium	1.41	8.05	3.57	19.85	0.42	2.62
Bulgaria	2.25	13.87	5.79	36.83	1.14	6.62
Croatia	0.77	4.57	2.13	12.24	0.04	0.43
Cyprus	1.19	6.84	3.59	20.30	0.09	0.65
Czech Republic	1.43	8.09	4.08	23.12	0.00	0.00
Denmark	1.39	8.06	3.27	18.31	0.19	1.51
Estonia	1.56	8.58	2.93	16.65	0.82	4.23
Finland	0.80	4.75	2.02	11.28	0.13	1.23
France	1.07	6.01	2.85	15.95	0.11	0.66
Germany	1.47	8.54	3.40	19.24	0.76	4.67
Greece	2.34	13.36	5.25	29.61	0.24	1.58
Hungary	1.33	7.25	3.22	17.87	0.31	1.52
Ireland	1.62	9.68	3.60	20.47	0.30	2.42
Italy	3.50	27.34	6.39	49.52	0.61	5.16
Latvia	1.69	9.55	5.85	32.68	0.31	1.84
Lithuania	1.34	7.75	3.70	21.07	0.06	0.58
Luxembourg	1.42	8.17	2.72	15.56	0.06	0.47
Malta	2.85	16.90	7.27	42.84	1.45	8.71
Netherlands	0.96	5.97	1.91	11.94	0.00	0.00
Poland	3.10	17.62	7.12	40.60	0.42	2.31
Portugal	1.99	12.19	4.17	23.59	0.48	4.26
Romania	3.17	17.89	4.65	26.19	0.41	2.49
Slovakia	2.13	15.25	5.60	38.51	0.26	2.73
Slovenia	1.11	6.82	2.39	13.80	0.29	2.35
Spain	0.56	3.27	1.35	7.85	0.19	1.16
Sweden	3.54	19.61	5.27	29.13	0.29	1.80
United Kingdom	2.00	11.36	5.45	30.87	0.15	0.85
Norway	1.98	11.56	4.91	28.42	0.26	1.66
Switzerland	1.32	7.52	3.29	18.86	0.26	1.41

[82] Based on the whole network (not only congested network).

Table 111 - Car average[83] delay congestion cost and deadweight loss brone per vkm (€-cent/vkm, in Euro2016)

Country	Deadweight loss	Delay cost	Deadweight loss	Delay cost	Deadweight loss	Delay cost
	Total (urban and inter-urban)		Urban		Inter-urban	
EU28	1.21	7.03	3.31	19.03	0.27	1.66
Austria	0.97	5.45	2.59	14.39	0.30	1.76
Belgium	1.51	9.23	4.04	25.69	0.71	4.03
Bulgaria	0.69	4.04	1.51	8.69	0.04	0.38
Croatia	0.87	4.98	2.81	15.92	0.07	0.48
Cyprus	1.47	8.31	3.33	18.88	-	-
Czech Republic	1.13	6.54	2.61	14.63	0.15	1.20
Denmark	1.12	6.06	2.12	12.03	0.58	2.85
Estonia	0.58	3.46	1.44	8.03	0.11	1.01
Finland	0.74	4.09	1.98	11.05	0.07	0.34
France	1.04	5.83	2.30	12.99	0.50	2.73
Germany	1.07	6.13	3.54	19.97	0.16	1.01
Greece	1.17	6.37	2.33	12.93	0.26	1.23
Hungary	1.19	7.04	2.89	16.46	0.22	1.69
Ireland	2.17	17.11	6.08	47.15	0.49	4.24
Italy	0.99	5.56	4.06	22.70	0.20	1.13
Latvia	0.95	5.51	2.63	14.94	0.05	0.43
Lithuania	0.85	4.93	2.14	12.25	0.05	0.44
Luxembourg	2.83	16.86	7.15	42.16	1.46	8.88
Malta	0.64	4.02	1.29	8.04	-	-
Netherlands	1.39	7.87	5.43	30.96	0.28	1.58
Poland	1.42	8.75	3.01	17.03	0.39	3.41
Portugal	1.63	9.33	3.88	21.85	0.41	2.59
Romania	2.12	15.08	4.47	30.75	0.26	2.77
Slovakia	0.89	5.49	1.86	10.73	0.25	2.02
Slovenia	0.38	2.20	0.92	5.37	0.15	0.89
Spain	1.51	8.44	3.79	20.95	0.29	1.70
Sweden	1.41	7.94	3.83	21.72	0.10	0.52
United Kingdom	1.51	8.77	3.52	20.35	0.18	1.14
Norway	0.90	5.07	2.25	12.91	0.18	0.85
Switzerland	0.92	5.25	2.05	11.98	0.46	2.48

[83] Based on the whole network (not only congested network).

Table 112 - Average[84] inter-urban delay congestion costs and deadweight loss borne for HGV, coaches and LCV (€-cent/vkm, in Euro2016)

Country	Deadweight loss			Delay cost		
	Trucks (HGV)	Coaches	LCVs*	Trucks (HGV)	Coaches	LCVs*
EU28	0.69	1.50	0.33	6.20	14.49	1.92
Austria	1.13	1.49	0.22	8.87	17.93	1.28
Belgium	2.97	12.76	0.85	24.90	36.24	4.87
Bulgaria	0.04	0.17	0.02	0.46	2.59	0.15
Croatia	0.17	0.28	0.04	1.45	3.32	0.27
Cyprus	-	-	-	-	-	-
Czech Republic	0.12	1.23	0.06	1.14	8.41	0.46
Denmark	0.92	4.41	0.58	7.59	30.46	2.88
Estonia	0.02	0.57	0.06	0.13	7.54	0.54
Finland	0.54	0.30	0.06	4.47	3.39	0.31
France	2.23	1.50	0.65	24.90	26.71	3.58
Germany	0.63	0.97	0.13	5.41	11.01	0.82
Greece	0.34	1.41	0.13	2.65	9.18	0.61
Hungary	0.43	1.07	0.11	2.99	12.07	0.85
Ireland	1.48	4.21	0.29	15.07	33.21	2.45
Italy	0.50	0.81	0.24	3.43	10.15	1.36
Latvia	0.10	0.26	0.03	0.91	2.88	0.25
Lithuania	0.03	2.75	0.03	0.16	3.36	0.21
Luxembourg	0.95	23.52	0.89	5.81	95.66	5.39
Malta	-	-	-	-	-	-
Netherlands	0.47	10.99	0.23	3.24	15.66	1.29
Poland	0.40	2.24	0.21	3.65	22.65	1.84
Portugal	0.85	3.34	0.19	7.31	20.73	1.10
Romania	0.22	0.73	0.08	2.26	14.99	0.78
Slovakia	0.18	2.13	0.11	1.70	12.82	0.88
Slovenia	0.07	0.65	0.10	0.46	8.10	0.59
Spain	0.76	1.36	0.15	6.51	13.99	0.82
Sweden	0.40	0.29	0.09	2.98	5.35	0.48
United Kingdom	0.44	1.63	0.16	3.43	11.00	0.98
Norway	0.63	0.72	0.20	6.10	9.06	0.93
Switzerland	1.73	7.00	0.39	18.16	27.51	2.05

* Estimated with a simplified approach based on estimated value of congestion costs for passenger cars.

84 Based on the whole network (not only congested network).

Table 113 - Average urban delay congestion costs and deadweight loss borne for trucks (€-cent/vkm, in Euro2016)

Country	Deadweight loss		Delay cost	
	HGVs	LCVs*	HGVs	LCVs*
EU28	9.11	3.31	51.94	19.21
Austria	8.67	2.42	48.14	13.42
Belgium	11.61	5.04	73.88	32.11
Bulgaria	3.32	0.93	19.08	5.32
Croatia	5.79	1.88	32.80	10.62
Cyprus	7.95	2.43	45.04	13.79
Czech Republic	4.74	1.17	26.58	6.58
Denmark	6.40	2.14	36.31	12.13
Estonia	3.42	1.02	19.07	5.68
Finland	9.69	1.85	54.19	10.35
France	9.09	3.14	51.42	17.77
Germany	11.47	3.33	64.71	18.77
Greece	8.34	1.69	46.32	9.37
Hungary	7.13	1.61	40.61	9.17
Ireland	10.56	4.23	81.87	32.77
Italy	11.91	5.26	66.56	29.39
Latvia	6.28	1.68	35.73	9.57
Lithuania	3.76	1.13	21.52	6.45
Luxembourg	16.71	4.10	98.47	24.13
Malta	3.16	1.33	19.72	8.31
Netherlands	14.45	4.83	82.36	27.52
Poland	7.19	1.71	40.67	9.68
Portugal	12.65	3.25	71.21	18.29
Romania	6.93	1.93	47.66	13.28
Slovakia	3.66	0.95	21.09	5.46
Slovenia	3.30	0.73	19.19	4.22
Spain	12.95	3.32	71.50	18.32
Sweden	15.36	3.70	87.03	20.96
United Kingdom	9.86	3.26	57.04	18.89
Norway	11.16	2.68	64.06	15.41
Switzerland	4.37	1.90	25.57	11.12

* Estimated with a simplified approach based on estimated valued for passenger cars.

Table 114 - Average inter-urban delay congestion costs and deadweight loss borne on motorway network (€-cent/vkm, in Euro2016)

Country	Deadweight loss				Delay cost			
	Car	Trucks (HGV)	Coaches	LCVs*	Car	Trucks (HGV)	Coaches	LCVs*
EU28	0.10	0.46	0.49	0.12	0.42	2.55	2.87	0.48
Austria	0.08	0.69	0.61	0.06	0.31	3.78	3.49	0.23
Belgium	0.24	1.67	2.03	0.29	0.97	9.21	11.70	1.17
Bulgaria	0.01	0.01	0.02	0.00	0.03	0.04	0.13	0.02
Croatia	0.02	0.05	0.08	0.01	0.06	0.27	0.48	0.04
Cyprus	-	-	-	-	-	-	-	-
Czech Republic	0.06	0.06	0.39	0.02	0.26	0.31	2.35	0.10
Denmark	0.17	0.65	1.43	0.16	0.69	3.55	8.33	0.66
Estonia	-	-	-	-	-	-	-	-
Finland	0.05	0.96	0.81	0.04	0.20	5.31	4.69	0.18
France	0.18	1.88	1.15	0.23	0.72	10.35	6.67	0.93
Germany	0.06	0.35	0.68	0.05	0.23	1.94	3.92	0.20
Greece	0.14	0.28	0.41	0.08	0.57	1.53	2.41	0.34
Hungary	0.23	0.83	0.90	0.11	0.91	4.43	5.05	0.45
Ireland	0.22	0.66	0.82	0.14	0.87	3.56	4.66	0.58
Italy	0.07	0.29	0.25	0.08	0.28	1.63	1.45	0.33
Latvia	-	-	-	-	-	-	-	-
Lithuania	0.11	0.04	0.45	0.05	0.43	0.21	2.58	0.21
Luxembourg	1.05	1.43	10.49	0.64	4.24	7.75	60.30	2.59
Malta	-			-	-			-
Netherlands	0.12	0.44	0.87	0.09	0.48	2.43	4.97	0.38
Poland	0.24	0.39	1.49	0.13	0.94	2.11	8.42	0.50
Portugal	0.16	0.26	0.60	0.10	0.64	1.45	3.53	0.43
Romania	0.05	0.04	0.10	0.02	0.19	0.23	0.59	0.07
Slovakia	0.06	0.03	0.37	0.03	0.27	0.19	2.18	0.12
Slovenia	0.10	0.06	0.69	0.07	0.42	0.36	4.06	0.28
Spain	0.07	0.26	0.28	0.06	0.28	1.41	1.59	0.25
Sweden	0.10	1.49	1.66	0.09	0.38	8.15	9.43	0.34
United Kingdom	0.05	0.20	0.53	0.04	0.21	1.12	3.09	0.18
Norway	0.00	0.03	0.08	0.00	0.02	0.18	0.48	0.02
Switzerland	0.24	0.64	2.05	0.21	1.00	3.60	12.01	0.86

* Estimated with a simplified approach based on estimated value of congestion costs for passenger cars.

F.7 Detailed estimated congestion costs by country - Marginal costs

Table 115 - Car social marginal congestion costs per vkm (€-cent/vkm, in Euro$_{2016}$)

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
EU28	32.1	24.8	17.4	66.3	58.2	47.2	29.4	22.6	15.9	46.4	39.6	31.2
Austria	35.6	27.5	19.4	73.6	64.6	52.4	32.6	25.2	17.7	51.5	44.0	34.6
Belgium	37.1	28.6	20.1	76.6	67.3	54.5	34.2	26.4	18.6	54.0	46.1	36.3
Bulgaria	20.6	15.9	11.2	42.5	37.3	30.2	18.5	14.3	10.1	29.3	25.0	19.7
Croatia	24.8	19.1	13.4	51.2	44.9	36.4	22.3	17.2	12.1	35.2	30.1	23.7
Cyprus	26.5	20.5	14.4	54.8	48.1	39.0	23.9	18.4	13.0	37.8	32.2	25.4
Czech Republic	35.2	27.2	19.1	72.7	63.9	51.8	32.3	25.0	17.6	51.1	43.6	34.3
Denmark	33.2	25.6	18.0	68.6	60.2	48.9	30.0	23.1	16.3	47.4	40.5	31.8
Estonia	27.6	21.3	15.0	57.1	50.1	40.6	25.6	19.8	13.9	40.5	34.6	27.2
Finland	31.9	24.6	17.3	65.9	57.9	46.9	29.2	22.5	15.9	46.1	39.4	31.0
France	30.5	23.6	16.6	63.1	55.4	44.9	27.7	21.4	15.0	43.7	37.3	29.4
Germany	32.1	24.8	17.5	66.4	58.3	47.3	29.5	22.8	16.0	46.7	39.8	31.4
Greece	25.5	19.7	13.9	52.7	46.3	37.5	23.6	18.2	12.8	37.3	31.8	25.1
Hungary	27.8	21.5	15.1	57.5	50.4	40.9	24.8	19.1	13.5	39.2	33.5	26.3
Ireland	63.0	48.6	34.2	130.1	114.2	92.6	60.3	46.5	32.7	95.2	81.3	64.0
Italy	30.6	23.6	16.6	63.2	55.5	45.0	27.8	21.5	15.1	44.0	37.5	29.6
Latvia	28.1	21.7	15.3	58.0	50.9	41.3	24.8	19.1	13.5	39.2	33.5	26.3
Lithuania	30.5	23.5	16.6	63.1	55.4	44.9	27.0	20.8	14.6	42.6	36.3	28.6
Luxembourg	70.0	54.0	38.0	144.6	127.0	103.0	63.6	49.1	34.6	100.5	85.8	67.6
Malta	29.0	22.4	15.8	60.0	52.7	42.7	26.2	20.2	14.2	41.3	35.3	27.8
Netherlands	38.1	29.4	20.7	78.7	69.1	56.0	34.1	26.3	18.5	53.8	45.9	36.2
Poland	28.5	22.0	15.5	58.8	51.6	41.9	26.3	20.3	14.3	41.5	35.5	27.9

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
Portugal	27.9	21.6	15.2	57.7	50.7	41.1	25.3	19.6	13.8	40.0	34.2	26.9
Romania	25.5	19.7	13.9	52.7	46.3	37.5	27.6	21.3	15.0	43.6	37.2	29.3
Slovakia	34.9	26.9	18.9	72.1	63.3	51.3	31.2	24.1	17.0	49.4	42.1	33.2
Slovenia	27.0	20.8	14.7	55.7	48.9	39.7	24.2	18.7	13.2	38.3	32.7	25.7
Spain	31.2	24.1	17.0	64.5	56.6	45.9	28.8	22.3	15.7	45.6	38.9	30.6
Sweden	34.8	26.8	18.9	71.8	63.1	51.1	31.9	24.6	17.3	50.4	43.1	33.9
United Kingdom	31.2	24.1	17.0	64.5	56.7	45.9	28.7	22.2	15.6	45.4	38.7	30.5
Norway	42.1	32.4	22.8	86.9	76.3	61.9	35.5	27.4	19.3	56.1	47.9	37.7
Switzerland	43.0	33.2	23.3	88.8	77.9	63.2	38.6	29.8	20.9	60.9	52.0	40.9
Canada[85]	24.1	18.6	13.1	49.8	43.7	35.5						
United States[86]	41.5	32.0	22.6	85.8	75.3	61.1						
Japan[87]	38.9	30.0	21.1	80.4	70.5	57.2						

Over capacity: flow to capacity ratio above 1.2.

Congested: flow to capacity ratio between 1.0 and 1.2.

Near capacity: flow to capacity ratio between 0.8 and 1.0.

85 Estimations for Alberta and British Columbia.

86 Estimations for California and Missouri.

87 Estimations based on the city of Tokyo.

Table 116 - Inter-urban social marginal congestion costs for trucks and coaches (€-cent/vkm, in Euro$_{2016}$)

Country	Trucks						Coaches					
	Motorways			Other road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
EU28	122.0	94.2	66.3	159.3	136.0	107.1	318.5	245.8	173.0	415.8	355.0	279.4
Austria	156.4	120.7	84.9	204.2	174.3	137.2	394.4	304.3	214.2	514.9	439.6	346.0
Belgium	140.9	108.7	76.5	183.9	157.0	123.6	363.7	280.6	197.5	474.8	405.3	319.1
Bulgaria	58.3	45.0	31.7	76.2	65.0	51.2	150.6	116.2	81.8	196.6	167.8	132.1
Croatia	65.9	50.8	35.8	86.0	73.4	57.8	185.5	143.2	100.8	242.2	206.8	162.8
Cyprus	81.7	63.1	44.4	106.7	91.1	71.7	256.6	198.0	139.4	335.0	286.0	225.1
Czech Republic	84.3	65.0	45.8	110.0	93.9	73.9	271.4	209.4	147.4	354.4	302.5	238.1
Denmark	129.8	100.2	70.5	169.5	144.7	113.9	382.7	295.3	207.9	499.7	426.6	335.8
Estonia	87.2	67.3	47.4	113.9	97.2	76.5	232.2	179.2	126.1	303.1	258.8	203.7
Finland	205.2	158.3	111.5	267.9	228.7	180.0	338.2	261.0	183.7	441.6	377.0	296.7
France	157.0	121.2	85.3	205.0	175.0	137.8	322.3	248.7	175.1	420.8	359.2	282.8
Germany	137.2	105.9	74.5	179.1	152.9	120.4	381.7	294.5	207.3	498.3	425.4	334.9
Greece	121.3	93.6	65.9	158.4	135.2	106.4	208.9	161.2	113.5	272.7	232.8	183.3
Hungary	87.8	67.7	47.7	114.6	97.8	77.0	208.9	161.2	113.5	272.7	232.8	183.3
Ireland	150.1	115.8	81.5	195.9	167.3	131.7	565.1	436.0	307.0	737.8	629.8	495.8
Italy	117.0	90.3	63.6	152.8	130.5	102.7	299.0	230.7	162.4	390.3	333.2	262.3
Latvia	85.1	65.6	46.2	111.1	94.8	74.6	199.3	153.8	108.3	260.2	222.2	174.9
Lithuania	67.8	52.4	36.9	88.6	75.6	59.5	233.3	180.0	126.7	304.5	260.0	204.7
Luxembourg	213.1	164.4	115.7	278.2	237.5	187.0	796.2	614.4	432.5	1039.5	887.4	698.6
Malta	91.9	70.9	49.9	120.0	102.4	80.6	291.6	225.0	158.4	380.7	325.0	255.8
Netherlands	129.9	100.2	70.6	169.6	144.8	114.0	394.4	304.3	214.2	514.9	439.6	346.0
Poland	90.1	69.5	48.9	117.6	100.4	79.0	211.0	162.8	114.6	275.5	235.2	185.1
Portugal	118.4	91.4	64.3	154.6	132.0	103.9	239.6	184.9	130.2	312.8	267.1	210.2
Romania	61.3	47.3	33.3	80.0	68.3	53.8	180.2	139.1	97.9	235.3	200.9	158.1
Slovakia	88.0	67.9	47.8	114.9	98.1	77.2	237.5	183.2	129.0	310.1	264.7	208.4
Slovenia	124.0	95.7	67.4	161.9	138.2	108.8	255.5	197.2	138.8	333.6	284.8	224.2
Spain	141.1	108.9	76.7	184.3	157.3	123.8	283.1	218.4	153.8	369.6	315.5	248.4

Country	Trucks						Coaches					
	Motorways			Other road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
Sweden	183.4	141.5	99.6	239.4	204.4	160.9	381.7	294.5	207.3	498.3	425.4	334.9
United Kingdom	115.4	89.0	62.7	150.7	128.6	101.2	332.9	256.9	180.8	434.6	371.0	292.1
Norway	252.8	195.1	137.3	330.1	281.8	221.8	459.1	354.2	249.4	599.4	511.7	402.8
Switzerland	118.0	91.0	64.1	154.0	131.5	103.5	498.3	384.5	270.7	650.6	555.4	437.2

Over capacity: flow to capacity ratio above 1.2.

Congested: flow to capacity ratio between 1.0 and 1.2.

Near capacity: flow to capacity ratio between 0.8 and 1.0.

Table 117 - Inter-urban social marginal congestion costs generated for HGV, estimated using the simplified approach (€-cent/vkm, in Euro$_{2016}$)

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
EU28	64.2	49.5	34.9	132.6	116.4	94.4	58.7	45.3	31.9	92.7	79.2	62.3
Austria	71.3	55.0	38.7	147.3	129.3	104.8	65.2	50.3	35.4	103.0	87.9	69.2
Belgium	74.2	57.2	40.3	153.2	134.5	109.1	68.3	52.7	37.1	108.0	92.2	72.5
Bulgaria	41.1	31.7	22.3	85.0	74.6	60.5	37.1	28.6	20.1	58.6	50.0	39.4
Croatia	49.5	38.2	26.9	102.3	89.8	72.8	44.6	34.4	24.2	70.5	60.2	47.4
Cyprus	53.1	40.9	28.8	109.7	96.3	78.1	47.8	36.9	26.0	75.5	64.5	50.8
Czech Republic	70.4	54.3	38.2	145.5	127.7	103.6	64.7	49.9	35.1	102.2	87.2	68.7
Denmark	66.4	51.3	36.1	137.3	120.5	97.7	60.0	46.3	32.6	94.8	80.9	63.7
Estonia	55.3	42.6	30.0	114.2	100.2	81.3	51.2	39.5	27.8	81.0	69.1	54.4
Finland	63.8	49.2	34.7	131.9	115.8	93.9	58.4	45.0	31.7	92.2	78.7	62.0
France	61.1	47.1	33.2	126.2	110.8	89.8	55.3	42.7	30.1	87.4	74.6	58.8
Germany	64.3	49.6	34.9	132.8	116.6	94.5	59.1	45.6	32.1	93.3	79.7	62.7
Greece	51.0	39.4	27.7	105.5	92.6	75.1	47.2	36.4	25.6	74.6	63.7	50.1
Hungary	55.6	42.9	30.2	114.9	100.9	81.8	49.6	38.3	27.0	78.4	66.9	52.7
Ireland	125.9	97.2	68.4	260.3	228.4	185.3	120.6	93.0	65.5	190.5	162.6	128.0
Italy	61.2	47.2	33.2	126.4	110.9	90.0	55.7	43.0	30.2	88.0	75.1	59.1
Latvia	56.2	43.3	30.5	116.1	101.9	82.6	49.6	38.3	27.0	78.4	66.9	52.7
Lithuania	61.0	47.1	33.2	126.1	110.7	89.8	53.9	41.6	29.3	85.2	72.7	57.2
Luxembourg	140.0	108.0	76.0	289.3	253.9	205.9	127.3	98.2	69.1	201.0	171.6	135.1
Malta	58.1	44.8	31.5	120.0	105.3	85.4	52.3	40.4	28.4	82.6	70.5	55.5
Netherlands	76.2	58.8	41.4	157.5	138.2	112.1	68.1	52.6	37.0	107.6	91.9	72.3
Poland	56.9	43.9	30.9	117.7	103.3	83.8	52.6	40.6	28.6	83.1	70.9	55.8
Portugal	55.9	43.1	30.3	115.4	101.3	82.2	50.7	39.1	27.5	80.1	68.4	53.8
Romania	51.0	39.4	27.7	105.4	92.5	75.0	55.2	42.6	30.0	87.2	74.4	58.6
Slovakia	69.8	53.8	37.9	144.2	126.5	102.6	62.5	48.2	33.9	98.7	84.3	66.3
Slovenia	54.0	41.6	29.3	111.5	97.9	79.4	48.4	37.4	26.3	76.5	65.3	51.4
Spain	62.4	48.2	33.9	129.0	113.2	91.8	57.7	44.5	31.3	91.1	77.8	61.2

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
Sweden	69.5	53.6	37.8	143.7	126.1	102.3	63.9	49.3	34.7	100.9	86.1	67.8
United Kingdom	62.5	48.2	33.9	129.1	113.3	91.9	57.4	44.3	31.2	90.7	77.5	61.0
Norway	84.1	64.9	45.7	173.8	152.6	123.7	71.1	54.8	38.6	112.2	95.8	75.4
Switzerland	85.9	66.3	46.7	177.6	155.9	126.4	77.1	59.5	41.9	121.8	104.0	81.9

Over capacity: flow to capacity ratio above 1.2.

Congested: flow to capacity ratio between 1.0 and 1.2.

Near capacity: flow to capacity ratio between 0.8 and 1.0.

Table 118 - Social marginal congestion costs generated for LCVs per vkm, estimated using the simplified approach (€-cent/vkm, in Euro2016)

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
EU28	48.1	37.1	26.1	99.4	87.3	70.8	44.0	34.0	23.9	69.6	59.4	46.7
Austria	53.5	41.2	29.0	110.5	97.0	78.6	48.9	37.7	26.6	77.3	66.0	51.9
Belgium	55.6	42.9	30.2	114.9	100.9	81.8	51.3	39.5	27.8	81.0	69.1	54.4
Bulgaria	30.8	23.8	16.8	63.7	56.0	45.4	27.8	21.5	15.1	43.9	37.5	29.5
Croatia	37.1	28.7	20.2	76.7	67.4	54.6	33.5	25.8	18.2	52.9	45.1	35.5
Cyprus	39.8	30.7	21.6	82.2	72.2	58.5	35.9	27.7	19.5	56.6	48.4	38.1
Czech Republic	52.8	40.7	28.7	109.1	95.8	77.7	48.5	37.4	26.3	76.6	65.4	51.5
Denmark	49.8	38.4	27.1	103.0	90.4	73.3	45.0	34.7	24.4	71.1	60.7	47.8
Estonia	41.4	32.0	22.5	85.6	75.2	61.0	38.4	29.7	20.9	60.7	51.8	40.8
Finland	47.9	36.9	26.0	98.9	86.8	70.4	43.8	33.8	23.8	69.2	59.0	46.5
France	45.8	35.3	24.9	94.7	83.1	67.4	41.5	32.0	22.5	65.6	56.0	44.1
Germany	48.2	37.2	26.2	99.6	87.4	70.9	44.3	34.2	24.1	70.0	59.8	47.0
Greece	38.3	29.5	20.8	79.1	69.4	56.3	35.4	27.3	19.2	55.9	47.8	37.6
Hungary	41.7	32.2	22.7	86.2	75.6	61.3	37.2	28.7	20.2	58.8	50.2	39.5
Ireland	94.5	72.9	51.3	195.2	171.3	138.9	90.4	69.8	49.1	142.9	122.0	96.0
Italy	45.9	35.4	24.9	94.8	83.2	67.5	41.8	32.2	22.7	66.0	56.3	44.3
Latvia	42.1	32.5	22.9	87.0	76.4	62.0	37.2	28.7	20.2	58.8	50.2	39.5
Lithuania	45.8	35.3	24.9	94.6	83.0	67.3	40.4	31.2	22.0	63.9	54.5	42.9
Luxembourg	105.0	81.0	57.0	217.0	190.4	154.4	95.4	73.6	51.8	150.8	128.7	101.3
Malta	43.6	33.6	23.7	90.0	79.0	64.1	39.2	30.3	21.3	62.0	52.9	41.7
Netherlands	57.2	44.1	31.0	118.1	103.7	84.1	51.1	39.4	27.8	80.7	68.9	54.2
Poland	42.7	33.0	23.2	88.2	77.5	62.8	39.4	30.4	21.4	62.3	53.2	41.9
Portugal	41.9	32.3	22.8	86.6	76.0	61.6	38.0	29.3	20.7	60.1	51.3	40.4
Romania	38.3	29.5	20.8	79.0	69.4	56.3	41.4	31.9	22.5	65.4	55.8	43.9
Slovakia	52.3	40.4	28.4	108.1	94.9	77.0	46.9	36.2	25.5	74.0	63.2	49.8
Slovenia	40.5	31.2	22.0	83.6	73.4	59.5	36.3	28.0	19.7	57.4	49.0	38.6
Spain	46.8	36.1	25.4	96.7	84.9	68.9	43.3	33.4	23.5	68.3	58.3	45.9

Country	Urban area						Inter-urban area					
	Trunk road			Other urban road			Motorways			Other road		
	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity	Over capacity	Congested	Near capacity
Sweden	52.1	40.2	28.3	107.8	94.6	76.7	47.9	37.0	26.0	75.7	64.6	50.8
United Kingdom	46.9	36.2	25.5	96.8	85.0	68.9	43.1	33.2	23.4	68.0	58.1	45.7
Norway	63.1	48.7	34.3	130.4	114.4	92.8	53.3	41.1	28.9	84.2	71.9	56.6
Switzerland	64.5	49.7	35.0	133.2	116.9	94.8	57.8	44.6	31.4	91.4	78.0	61.4

Over capacity: flow to capacity ratio above 1.2.

Congested: flow to capacity ratio between 1.0 and 1.2.

Near capacity: flow to capacity ratio between 0.8 and 1.0.

F.8 Congestion and scarcity costs for other transport modes

This annex gathers the main findings from the literature review conducted on congestion costs of the other transport modes.

For **rail** Rotoli et al. (2016) reviewed different analytical and optimisation procedures to evaluate rail networks capacity. The level of detail, data availability and complexity has been linked with the evaluation of utilised capacity, and in turn, with the probability of expected 'reactionary delay'. The methodologies considered were the UIC's Analytical Method (Code 405R) and Compression Method (Code 406), the Capacity Utilisation Index (CUI) Method and the STRELE Formula (i.e., Method of Schwanhäußer). The analysis suggests that the methodologies considered are a useful way to estimate the congestion and the trade-offs between capacity of a railway network, delays and related costs.

Vromans et al. (2006) and Haith et al. (2014) suggested an alternative methodology to CUI, based on the theory that the level of 'reactionary delay' can be determined by the minimum gaps that exist between trains.

Brunel et al. (2013) analysed the relationship between traffic density (i.e., number of trains per hour), reliability rate and average delay in order to assess rail congestion. The analysis focussed on 42 lines of the French rail network estimating to what extent the delay of a train (i.e., direct delay) impacts on another train (i.e., indirect delay). Estimations were diversified for 9 different categories to account for the type of train (i.e., high speed, intercity and regional) and traffic density (i.e., low, medium and high). However, the authors did not develop estimations of the marginal costs in monetary terms.

Jansson and Lang (2013) developed a methodology to evaluate the external delay costs in rail transport. In the application for passengers transport in Sweden, the authors estimated, how the marginal cost-based charges (initially limited to external costs for wear and tear, maintenance, emissions, etc.) would change if delays due to additional departures were also taken into account. For example, if an additional departure of a commuter train leads to a delay of two minutes in the network shared with high speed trains, the authors estimated the marginal external cost effect of this delay to correspond to a 25% increase in the commuter train fare for this additional journey, and a 5% increase in the fares for high speed trains.

Maritime shipping: By considering cargo handling and port logistics (stevedoring) costs and wait time records at several international ports of the 1970s, the UNITE project (Doll, 2002)concludes that there are no external congestion costs in seaport operations.
The analysis of EU and US ports in the COMPETE project (Schade, et al., 2006) however,clearly show that capacity in particular in North American ports is approaching its limits and that congestion at cargo handling and storage facilities is a priority issue. The GRACE D4 report (Meersman, et al., 2006) estimates the additional (marginal) crew costs of a vessel having to wait to call at a port at € 185 per hour. However, as ports usually do not keep records of vessel waiting times the calculation of price relevant marginal external congestion costs in maritime transport is not easy to carry out.

Inland navigation: COMPETE results suggest that European countries do not face any capacity problems in their inland waterway networks. However, the GRACE case studies found a number of local bottlenecks at locks, although they largely depend on local conditions. Delay times range between zero and 160 minutes, in the latter case passage costs per ship are found to increase by € 50 if demand increases by 1%. Besides lock capacity, the availability of sufficiently deep water levels to operate all vessel types is a problem, particularly in summer time. Based on the Low Water Surcharge, which has to be paid on the river Rhine when water levels fall below a certain value.

Table 119 - Marginal external costs of congestion of rail freight transport €-cent/1,000 tkm (2016 prices)

Country	Value
Austria	35.74
Belgium	35.89
Bulgaria	65.25
Cyprus	n.a.
Czech Republic	43.56
Denmark	32.01
Estonia	63.54
Finland	36.30
France	33.64
Germany	32.96
Greece	42.49
Hungary	53.37
Ireland	41.30
Italy	31.60
Latvia	62.60
Lithuania	51.76
Luxembourg	46.23
Malta	n.a.
Netherlands	32.87
Poland	47.47
Portugal	34.30
Romania	120.82
Slovakia	58.62
Slovenia	49.44
Spain	40.40
Sweden	37.31
United Kingdom	37.01
EU average	43.20

Source: (Christidis & Brons, 2016).

G Detailed assessment costs of habitat damage

G.1 Introduction

Transport has different effects on nature and landscape or natural habitats. The main effects reported in literature are habitat loss (ecosystem loss), habitat fragmentation and negative effects on ecosystems due to the emissions of air pollutants (e.g. biodiversity loss). The following chapter summarizes the most important impacts of transport on natural habitats (i.e. nature and landscape). Section G.2 gives an overview on the latest literature, Section G.3 draws conclusions on how to proceed in the present Handbook.

G.2 Detailed discussion on impacts on natural habitats (nature and landscape)

The different negative effects of transport on nature and landscape can be described as the following:
- **Habitat loss:** Transport infrastructure requires land and/or natural surfaces. Therefore, transport infrastructure also leads to a loss of natural ecosystems, which are natural habitats of plants and animals. The land use of transport therefore leads to a loss of habitats (ecosystems), which has a negative effect on biodiversity. Habitat loss is occurring during the building phase of a transport infrastructure, but will last over the whole lifetime of a transport infrastructure.
- **Habitat fragmentation:** Transport infrastructure can also have additional fragmentation and separation effects for animals. These fragmentation effects can negatively affect the natural habitats of certain species and lead to adverse effects for species and consequently on biodiversity. Habitat fragmentation due to transport infrastructure is aconsequence of the infrastructure itself plus the transport demand on the infrastructure. The main negative effects are caused by large and broad main infrastructures such as motorways and high-speed rail lines. Large wildlife mammals such as deer, rabbit, badger, etc. as well as smaller animals such as amphibians are negatively affected of habitat fragmentation.
- **Habitat degradation due to emissions:** Habitat degradation can also occur via the emission of air pollutants of other toxic substances (e.g. heavy metals, PAH) or road salt. These effects again lead to biodiversity loss and therefore external costs.
  The *biodiversity loss due to air pollution* is already covered in the air pollution Chapter (4), where all adverse impacts of air pollution are included. The negative effects of the emission of toxic substances are covered in a separate chapter ('other external costs').
- **Visual intrusion (landscape scenery):** Transport infrastructure often also have a negative impact on the landscape and its scenery. This is not a negative effect for the environment, but is anthropogenic and negatively affecting inhabitants or visitors of a region (landscape). This effect is generally not quantified since it is very much dependent on the specific situation.
- **Invasive plants:** Invasive plants are appearing very often along transport infrastructure and are sometimes even spread thanks to transport infrastructure.
- **Light emmissions:** The emission (and immission) of light of transport vehicles during the night can negatively impact natural ecosystems (e.g. natural fauna).

In external costs literature, the first effect — habitat loss — has been discussed in several studies. Also the habitat fragmentation has been analysed in certain studies. Habitat degradation has been an issue in several studies when focussing on the emission of air pollutants and toxic substances. Other effects have not been quantitatively analysed and reported in the literature.

The corresponding Chapter (9) is therefore focussing on the habitat damage, i.e. the first of the three effects described above.

G.3 Assessment of costs of impacts on natural habitats (nature and landscape)

G.3.1 Recommended approach previous Handbook

The cost of impacts on nature and landscape has not been covered in the last Handbook.

G.3.2 New evidence

There are only few studies covering the external costs of habitat damage due to transport activities. A brief overview on the relevant literature is given in the following table.

Table 120 - Literature on external costs of habitat damage due to transport activities

Literature	Title of Study and main focus	Effects covered	Results, type of cost factors
INFRAS, IWW 2004 (UIC)	External costs of transport in Europe	Habitat loss: unsealing costs, restoration costs	Total and average costs: € and €/pkm, €/tkm
(Nateco; Econcept, 2004)	External costs of transport due to impacts on nature and landscape (first bottom-up calculation)	Habitat loss & fragmentation: restoration cost approached; bottom-up calculation based on aerial photo analysis	Total and average costs: CHF and CHF/pkm, CHF/tkm
(NEEDS, 2006a)	Assessment of Biodiversity Losses; Report of the EU-research project NEEDS	Habitat loss: restoration costs	Cost factors per m^2 and ecosystem type
DG MOVE 2008 (Infras, CE Delft, ISI & University of Gdansk, 2008)	1st Handbook on estimation of external costs of transport	Costs of nature and landscape: only short overview on the relevant effects and data	Only qualitative information and some selective cost factors from NEEDS and INFRAS, IWW 2004
(CE Delft, INFRAS & Fraunhofer ISI, 2011)	External costs of transport in Europe for 2008	Habitat loss: unsealing costs, restoration costs	Total and average costs: € and €/pkm, €/tkm
(UBA, 2018)	Methodenkonvention 3.0 on the estimation of environmental costs	Habitat loss & fragmentation, based on (INFRAS en Ecoplan, 2018)	Cost factors per vehicle type: €/vkm and €/pkm, €/tkm
(INFRAS en Ecoplan, 2018)	External costs of transport in Switzerland 2015 (update study, bottom-up calculation)	Habitat loss & fragmentation	Total costs and average costs: CHF/pkm, CHF/tkm

G.3.3 Conclusions

The most detailed bottom-up calculations of the cost of habitat damage have been made by the European research project NEEDS (2006) and in the latest Swiss study by INFRAS, Ecoplan (2018). Additionally, the most recent UBA study (UBA, 2018) also covers up-to-date cost factors for the negative effects on habitats, mainly also based on INFRAS, Ecoplan (2018).

In the main Chapter 9, the calculation of cost factors for nature and landscape focusses on habitat damage (habitat loss and fragmentation) and is mainly based on the most recent bottom-up study on external costs of transport in Switzerland (INFRAS en Ecoplan, 2018).

H Total and average costs motorways

H.1 Introduction

This section presents the total and average external costs for motorways only.

H.2 Total external costs of transport on motorways in the EU28

The total external costs of transport on motorways are shown in Table 121.

H.3 Average external costs of transport on motorways in the EU28

The average external costs of transport on motorways are shown in Table 122.

Table 121 - Total external costs of transport on motorways in the EU28 (billion €)

<table>
<tr><th rowspan="2">Vehicle category</th><th rowspan="2">Accidents</th><th rowspan="2">Air pollution</th><th rowspan="2">Climate change</th><th rowspan="2">Noise</th><th colspan="2">Congestion</th><th rowspan="2">WTT emissions</th><th rowspan="2">Habitat damage</th><th rowspan="2">Total (congestion based on delay costs genereated)</th><th rowspan="2">Total (congestion based on deadweight loss costs genereated)</th></tr>
<tr><th>Delay costs</th><th>Deadweight loss costs</th></tr>
<tr><td>Passenger car</td><td rowspan="3">13.5</td><td>6.08</td><td>12.99</td><td>7.7</td><td rowspan="3">3.2</td><td rowspan="3">0.7</td><td>4.24</td><td>9</td><td>56.71</td><td>54.21</td></tr>
<tr><td>Passenger car - petrol</td><td>1.55</td><td>7.08</td><td>4</td><td>2.31</td><td>5.1</td><td></td><td></td></tr>
<tr><td>Passenger car - diesel</td><td>4.58</td><td>5.87</td><td>3.7</td><td>1.92</td><td>3.9</td><td></td><td></td></tr>
<tr><td>Motorcycle</td><td>1</td><td>0.31</td><td>0.28</td><td>1.1</td><td>n/a</td><td>n/a</td><td>0.16</td><td>0.13</td><td colspan="2">2.98</td></tr>
<tr><td>Bus</td><td rowspan="2">0.2</td><td>0.02</td><td>0.03</td><td>0</td><td rowspan="2">0.1</td><td rowspan="2">0.02</td><td>0.01</td><td>0.01</td><td rowspan="2">1.75</td><td rowspan="2">1.67</td></tr>
<tr><td>Coach</td><td>0.31</td><td>0.43</td><td>0.3</td><td>0.14</td><td>0.2</td></tr>
<tr><td>LCV</td><td>1.9</td><td>3.01</td><td>3.15</td><td>1.5</td><td>0.9</td><td>0.2</td><td>0.9</td><td>1.3</td><td>12.66</td><td>11.96</td></tr>
<tr><td>HGV</td><td>5.5</td><td>1.93</td><td>2.63</td><td>2.3</td><td>0.4</td><td>0.1</td><td>1.04</td><td>1.56</td><td>15.36</td><td>15.06</td></tr>
</table>

Table 122 - Average external costs of transport on motorways in the EU28

<table>
<tr><th rowspan="2">Vehicle category</th><th rowspan="2">Accidents</th><th rowspan="2">Air pollution</th><th rowspan="2">Climate change</th><th rowspan="2">Noise</th><th colspan="2">Congestion</th><th rowspan="2">WTT emissions</th><th rowspan="2">Habitat damage</th><th rowspan="2">Total (congestion based on delay costs)</th><th rowspan="2">Total (congestion based on deadweight loss costs)</th></tr>
<tr><th>Delay costs</th><th>Deadweight loss costs</th></tr>
<tr><td colspan="11">Passenger transport (€-cent per pkm)</td></tr>
<tr><td>Passenger car</td><td rowspan="3">1.22</td><td>0.55</td><td>1.17</td><td>0.69</td><td rowspan="3">0.29</td><td rowspan="3">0.06</td><td>0.38</td><td>0.81</td><td>5.10</td><td>4.88</td></tr>
<tr><td>Passenger car - petrol</td><td>0.26</td><td>1.2</td><td>0.68</td><td>0.39</td><td>0.20</td><td></td><td></td></tr>
<tr><td>Passenger car - diesel</td><td>0.88</td><td>1.13</td><td>0.71</td><td>0.37</td><td>0.20</td><td></td><td></td></tr>
<tr><td>Motorcycle</td><td>3.57</td><td>1.12</td><td>1.01</td><td>3.88</td><td>n/a</td><td>n/a</td><td>0.57</td><td>0.48</td><td colspan="2">10.86</td></tr>
<tr><td>Bus</td><td rowspan="2">0.14</td><td>0.28</td><td>0.38</td><td>0.17</td><td rowspan="2">0.07</td><td rowspan="2">0.01</td><td>0.14</td><td>0.17</td><td>1.18</td><td>1.12</td></tr>
<tr><td>Coach</td><td>0.22</td><td>0.31</td><td>0.22</td><td>0.1</td><td>0.14</td><td>1.19</td><td>1.14</td></tr>
<tr><td colspan="11">LCV (€-cent per vkm)</td></tr>
<tr><td>LCV</td><td>1.81</td><td>2.89</td><td>3.03</td><td>1.46</td><td>0.94</td><td>0.21</td><td>0.87</td><td>1.25</td><td>12.51</td><td>11.78</td></tr>
<tr><td colspan="11">Freight transport (€-cent per tkm)</td></tr>
<tr><td>HGV</td><td>0.96</td><td>0.33</td><td>0.45</td><td>0.3-0.9</td><td>0.07</td><td>0.02</td><td>0.18</td><td>0.27</td><td>2.55-3.15</td><td>2.55-3.10</td></tr>
</table>

I EU27 values

I.1 Introduction

This section presents the total and average external costs for road, rail and inland waterways at the EU27 level (excluding the UK).

I.2 Total external costs of transport in the EU27

The total external costs of transport in the EU27 are shown in Table 123 and Table 124.

Table 123 - Total external costs of transport in the EU27 (billion €)

Vehicle category	Accidents	Air pollution	Climate change	Noise	Congestion		WTT emissions	Habitat damage	Total (congestion based on delay costs)	Total (congestion based on deadweight loss costs)
					Delay costs	Deadweight loss costs				
Road										
Passenger car	185.4	30.9	48.3	23.7	163.4	27.9	15.9	24.3	**491.9**	**356.4**
Passenger car - petrol		7.9	27.4	12.3			9.0	13.1		
Passenger car - diesel		23.1	20.8	11.3			6.9	11.2		
Motorcycle	19.1	1.8	1.4	14.4	n/a	n/a	0.8	0.5	**38.0**	
Bus	4.4	1.3	0.8	0.7	4.0	0.7	0.3	0.2	**17.2**	**13.9**
Coach		2.5	1.4	0.8			0.5	0.4		
LCV	17.3	14.1	11.6	4.9	47.5	8.1	3.3	4.1	**102.8**	**63.4**
HGV	21.0	13.2	8.6	8.5	13.0	2.2	3.4	3.4	**71.1**	**60.3**
Rail										
High speed passenger train	0.062	0.002	0	0.341	n/a	n/a	0.307	0.662	**1.4**	
Conventional electric passenger train	1.932	0.027	0	2.431	n/a	n/a	2.402	1.338	**10.0**	
Conventional diesel passenger train		0.444	0.173	0.700	n/a	n/a	0.060	0.448		
Electric freight train	0.270	0.012	0	2.063	n/a	n/a	0.497	0.773	**5.1**	
Diesel freight train		0.622	0.208	0.335	n/a	n/a	0.115	0.209		
IWT										
IWT Vessel	0.089	1.927	0.395	n/a	n/a	n/a	0.197	0.285	**2.9**	

Table 124 - Total external costs of transport for selected (air)ports in the EU27 (billion €)

	Accidents	Air pollution	Climate change	Noise	Congestion	WTT emissions	Habitat damage	Total
Aviation								
Selected EU27 airports	0.07	0.92	18.53	0.47	n/a	7.43	0.05	**27.47**
Maritime								
Selected EU27 ports	0.07	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**

J Marginal cost figures

J.1 Introduction

This section presents an overview of the marginal cost figures for selected cases for all modes in Section J.2.

Sections J.3, J.4 and J.5 present additional marginal cost figures for the categories air pollution, climate change and well-to-tank for the reference vehicles that have been defined for road. These reference vehicles have been used for the overview in Sections 4.4, 5.4 and 8.4. They have been based on the main cost drivers for climate and WTT cost which are the combination of fuel type and fuel efficiency. These have been combined with the main cost drivers for air pollution, which are the Euro standard and road type (for cars and LCVs).

J.2 Overview marginal external costs

This section provides a synthesis of the marginal external costs for the selected reference cases. With reference to road congestion, the values of social marginal congestion cost generated by vehicle type have been used (see Section 7.4.4).

J.2.1 Road

Table 125 - Synthesis of marginal external costs 2016 for EU28 - passenger cars (in €-cent/pkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs for dense metropolitan traffic during the day							
2016 Euro 6 fuel efficient petrol car: 141 g/km		0.14	1.00			0.26	
2016 Euro 6 fuel inefficient petrol car: 256 g/km		0.14	1.81			0.48	
2000 Euro 3 fuel efficient petrol car: 176 g/km		0.19	1.26			0.43	0.0
2000 Euro 3 fuel inefficient petrol car: 243 g/km		0.19	1.74			0.63	
2016 Euro 6 fuel efficient diesel car: 126 g/km		0.86	0.88			0.14	
2016 Euro 6 fuel inefficient diesel car: 169 g/km	1.41	0.86	1.18	0.5	41.2	0.19	
2000 Euro 3 fuel efficient diesel car: 147 g/km		1.90	1.02			0.22	0.0
2000 Euro 3 fuel inefficient diesel car: 192 g/km		1.90	1.34			0.29	
LPG Euro 6		0.19	0.83			0.18	0.0
CNG Euro 6		0.15	1.36			0.29	0.0
Full electric Euro 6		0.05	0.00			0.83	0.0
PHEV Euro 6 - petrol		0.06	0.22			0.08	0.0

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs for dense traffic on rural motorways during the day							
2016 Euro 6 fuel efficient car: 141 g/km	0.25	0.08	0.86	0.04	18.2	0.23	0.0
2016 Euro 6 fuel inefficient car: 256 g/km		0.08	1.56			0.41	
2000 Euro 3 fuel efficient car: 176 g/km		0.11	1.08			0.37	
2000 Euro 3 fuel inefficient car: 243 g/km		0.11	1.49			0.54	
2016 Euro 6 fuel efficient diesel car: 126 g/km		0.46	0.79			0.13	0.0
2016 Euro 6 fuel inefficient diesel car: 169 g/km		0.46	1.06			0.17	
2000 Euro 3 fuel efficient diesel car: 147 g/km		0.95	0.93			0.20	
2000 Euro 3 fuel inefficient diesel car: 192 g/km		0.95	1.21			0.26	
LPG Euro 6		0.12	0.75			0.16	0.0
CNG Euro 6		0.08	1.24			0.27	0.0
Full electric Euro 6		0.05	0.00			0.83	0.0
PHEV Euro 6 - petrol		0.06	0.29			0.10	0.0

Table 126 - Synthesis of marginal external costs 2016 for EU28 - motorcycles and mopeds (in €-cent/pkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs for dense metropolitan traffic during the day							
Fuel efficient Euro 3 motorcycle: 100 g/km	4.42	0.32	0.92	7.4	n/a	0.33	0.0
Fuel inefficient Euro 3 motorcycle: 128 g/km		0.32	1.27			0.46	
Moped		1.20	0.44			0.16	
Electric motorcycle		0.02	0.00			0.15	
Marginal costs for dense traffic on rural motorways during the day							
Fuel efficient Euro 3 motorcycle: 100 g/km	-0.65	0.29	1.11	0.06	n/a	0.40	0.0
Fuel inefficient Euro 3 motorcycle: 128 g/km		0.29	1.34			0.48	
Moped		0.53	0.44			0.16	
Electric motorcycle		0.02	0.00			0.15	

Table 127 - Synthesis of marginal external costs 2016 for EU28 - buses (in €-cent/pkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs for dense metropolitan traffic during the day							
Fuel efficient Euro 6 bus: 954 g/km	**0.80**	0.12	0.76	0.5	6.8	0.18	0.0
Fuel inefficient Euro 6 bus: 1,155 g/km		0.12	0.93			0.20	
Fuel efficient Euro 3 bus: 954 g/km		1.93	0.76			0.18	
Fuel inefficient Euro 3 bus: 1,155 g/km		1.93	0.93			0.20	
CNG Euro 6		0.53	0.06			0.01	
Full electric bus		0.04	0.00			0.63	
Marginal costs for dense traffic on rural motorways during the day							
Fuel efficient Euro 6 bus: 954 g/km	0.05	0.02	0.46	0.04	3.0	0.11	0.0
Fuel inefficient Euro 6 bus: 1,155 g/km		0.02	0.54			0.13	
Fuel efficient Euro 3 bus: 954 g/km		0.41	0.46			0.11	
Fuel inefficient Euro 3 bus: 1,155 g/km		0.41	0.54			0.13	
CNG Euro 6		0.15	0.06			0.01	
Full electric bus		0.01	0.00			0.63	

Table 128 - Synthesis of marginal external costs 2016 for EU28 - coaches (in €-cent/pkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs for dense metropolitan traffic during the day							
Fuel efficient Euro VI coach: 583 g/km	0.80	0.21	0.56	0.3	6.8	0.11	0.0
Fuel inefficient Euro VI coach: 742 g/km		0.17	0.75			0.13	
Fuel efficient Euro VI coach: 583 g/km		1.34	0.56			0.11	
Fuel inefficient Euro VI coach: 742 g/km		1.34	0.75			0.13	
Marginal costs for dense traffic on rural motorways during the day							
Fuel efficient Euro VI coach: 583 g/km	0.05	0.02	0.28	0.02	3.0	0.05	0.0
Fuel inefficient Euro VI coach: 742 g/km		0.02	0.34			0.06	
Fuel efficient Euro VI coach: 583 g/km		0.34	0.28			0.05	
Fuel inefficient Euro VI coach: 742 g/km		0.34	0.34			0.06	

Table 129 – Synthesis of marginal external costs 2016 for EU28 – LCVs (in €-cent/vkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs for dense metropolitan traffic during the day							
2016 fuel efficient Euro 6 LCV: 137 g/km	0.76	0.16	1.65	1.7	99.4	0.48	0.0
2016 fuel inefficient Euro 6 LCV: 233 g/km		0.16	2.80			0.81	
2000 fuel efficient Euro 3 LCV: 216 g/km		0.33	2.82			0.97	
2000 fuel inefficient Euro 3 LCV: 286 g/km		0.33	3.74			1.29	
2016 fuel efficient Euro 6 LCV 135 g/km		2.19	1.44			0.29	0.0
2016 fuel inefficient Euro 6 LCV: 173 g/km		2.19	1.85			0.37	
2000 fuel efficient Euro 3 LCV: 188 g/km		4.66	2.00			0.47	
2000 fuel inefficient Euro 3 LCV:245 g/km		4.66	2.61			0.62	
Full electric		0.08	0.00			2.37	0.0
Marginal costs for dense traffic on rural motorways during the day							
2016 fuel efficient Euro 6 LCV: 137 g/km	0.37	0.14	1.28	0.01	44.0	0.37	0.0
2016 fuel inefficient Euro 6 LCV: 233 g/km		0.14	2.18			0.63	
2000 fuel efficient Euro 3 LCV: 216 g/km		0.25	1.94			0.67	
2000 fuel inefficient Euro 3 LCV: 286 g/km		0.25	2.57			0.89	
2016 fuel efficient Euro 6 LCV 135 g/km		1.94	1.39			0.28	0.0
2016 fuel inefficient Euro 6 LCV: 173 g/km		1.94	1.78			0.35	
2000 fuel efficient Euro 3 LCV: 188 g/km		2.26	2.18			0.52	
2000 fuel inefficient Euro 3 LCV:245 g/km		2.26	2.84			0.67	
Full electric		0.10	0.00			2.37	0.0

Table 130 – Synthesis of marginal external costs 2016 for EU28 – HGVs (in €-cent/tkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs for dense metropolitan traffic during the day							
Fuel efficient HGV: 370 g/km Euro VI - diesel (3.5-7.5 t)	0.10	0.34	1.00	1.5	9.7	0.22	0.0
Low fuel efficiency Euro VI - diesel (3.5-7.5 t)		0.34	1.39			0.32	
Fuel efficient HGV: 370 g/km Euro III - diesel (3.5-7.5 t)		2.59	1.00			0.22	
Low fuel efficiency Euro III - diesel (3.5-7.5 t)		2.59	1.39			0.32	
Fuel efficient HGV: 596 g/km Euro VI - diesel (7.5-16 t)		0.14	0.66	0.7		0.15	
Fuel inefficient HGVs: 716 g/km Euro VI - diesel (7.5-16 t)		0.14	0.83			0.19	
Fuel efficient HGV: 596 g/km Euro III - diesel (7.5-16 t)		1.61	0.66			0.15	
Fuel inefficient HGVs: 716 g/km Euro III - diesel (7.5-16 t)		1.61	0.83			0.19	
Fuel inefficient HGVs: 716 g/km Euro VI - diesel (16-32 t)		0.14	0.58	0.6		0.14	
Fuel inefficient HGVs: 875 g/km Euro VI - diesel (16-32 t)		0.14	0.74			0.17	
Fuel inefficient HGVs: 716 g/km Euro III - diesel (16-32 t)		1.84	0.58			0.14	
Fuel inefficient HGVs: 875 g/km Euro III - diesel (16-32 t)		1.84	0.74			0.17	
Fuel efficient HGV: 848 g/km Euro VI - diesel (> 32 t)		0.11	0.66	0.6		0.15	
Fuel inefficient HGVs: 1,033 g/km Euro VI - diesel (>32t)		0.11	0.83			0.19	
Fuel efficient HGV: 848 g/km Euro III - diesel (> 32 t)		1.69	0.66			0.15	
Fuel inefficient HGVs: 1,033 g/km Euro III - diesel (> 32 t)		1.69	0.83			0.19	
LNG Euro 6 (> 32 t)		0.09	0.72			0.04	
Marginal costs for dense traffic on rural motorways during the day							
Fuel efficient HGV: 370 g/km Euro VI - diesel (3.5-7.5 t)	0.07	0.06	1.00	0.01	4.3	0.23	0.0
Low fuel efficiency Euro VI - diesel (3.5-7.5 t)		0.06	1.14			0.27	
Fuel efficient HGV: 370 g/km Euro III - diesel (3.5-7.5 t)		1.01	1.00			0.23	
Low fuel efficiency Euro III - diesel (3.5-7.5 t)		1.01	1.14			0.27	
Fuel efficient HGV: 596 g/km Euro VI - diesel (7.5-16 t)		0.03	0.49	0.01		0.11	
Fuel inefficient HGVs: 716 g/km Euro VI - diesel (7.5-16 t)		0.03	0.58			0.14	

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Fuel efficient HGV: 596 g/km Euro III - diesel (7.5-16 t)		0.50	0.49			0.11	
Fuel inefficient HGVs: 716 g/km Euro III - diesel (7.5-16 t)		0.50	0.58			0.14	
Fuel inefficient HGVs: 716 g/km Euro VI - diesel (16-32 t)		0.03	0.37			0.09	
Fuel inefficient HGVs: 875 g/km Euro VI - diesel (16-32 t)		0.03	0.44	0.005		0.10	
Fuel inefficient HGVs: 716 g/km Euro III - diesel (16-32 t)		0.50	0.37			0.09	
Fuel inefficient HGVs: 875 g/km Euro III - diesel (16-32 t)		0.50	0.44			0.10	
Fuel efficient HGV: 848 g/km Euro VI - diesel (> 32 t)		0.03	0.41			0.10	
Fuel inefficient HGVs: 1,033 g/km Euro VI - diesel (> 32 t)		0.03	0.49			0.11	
Fuel efficient HGV: 848 g/km Euro III - diesel (> 32 t)		0.44	0.41	0.005		0.10	
Fuel inefficient HGVs: 1,033 g/km Euro III - diesel (> 32 t)		0.44	0.49			0.11	
LNG Euro 6 (> 32 t)		0.02	0.42			0.03	

J.2.2 Rail

Table 131 – Synthesis of marginal external costs 2016 for EU28 – passenger trains (in €-cent/pkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs on dense metropolitan railways during the day							
High speed trains	0.1	0.002	0	0.13		0.39	0.0
Electric intercity		0.01	0	0.45		0.73	0.0
Diesel intercity with EGR/SCR		0.47	0.201	0.45		0.18	0.0
Diesel intercity without EGR/SCR		0.70	0.201	0.45		0.18	
Electric regional train	0.3	0.02	0	0.45	n/a	0.89	0.0
Diesel regional train with EGR/SCR		1.52	0.735	0.45		0.26	0.0
Diesel regional train without EGR/SCR		2.10	0.735	0.45		0.26	
Marginal costs on dense rural railways during the day							
High speed trains	0.1	0.002	0	0.01		0.39	0.0
Electric intercity		0.01	0	0.03		0.73	0.0
Diesel intercity with EGR/SCR		0.23	0.201	0.03		0.18	0.0
Diesel intercity without EGR/SCR		0.40	0.201	0.03		0.18	
Electric regional train	0.3	0.02	0	0.03	n/a	0.89	0.0
Diesel regional train with EGR/SCR		0.71	0.735	0.03		0.26	0.0
Diesel regional train without EGR/SCR		1.20	0.735	0.03		0.26	

Table 132 - Synthesis of marginal external costs 2016 for EU28 - freight trains (in €-cent/tkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Marginal costs on dense metropolitan railways during the day							
Electric long container		0.004	0	0.13		0.11	
Electric long bulk		0.004	0	0.13		0.10	
Electric short container		0.004	0	0.13		0.26	
Electric short bulk		0.004	0	0.13		0.18	
Diesel long container with EGR/SCR		0.13	0.158	0.13		0.03	
Diesel long container without EGR/SCR		0.28	0.158	0.13		0.03	
Diesel long bulk with EGR/SCR	**0.1**	0.11	0.087	0.13	n/a	0.03	0.0
Diesel long bulk without EGR/SCR		0.25	0.087	0.13		0.03	
Diesel short container with EGR/SCR		0.36	0.074	0.13		0.07	
Diesel short container without EGR/SCR		0.78	0.074	0.13		0.07	
Diesel short bulk with EGR/SCR		0.24	0.066	0.13		0.05	
Diesel short bulk without EGR/SCR		0.52	0.066	0.13		0.05	
Marginal costs on dense rural railways during the day							
Electric long container		0.002	0	0.001		0.11	
Electric long bulk		0.002	0	0.001		0.10	
Electric short container		0.002	0	0.001		0.26	
Electric short bulk		0.002	0	0.001		0.18	
Diesel long container with EGR/SCR		0.07	0.071	0.001		0.03	
Diesel long container without EGR/SCR		0.14	0.071	0.001		0.03	
Diesel long bulk with EGR/SCR	**0.1**	0.06	0.067	0.001	n/a	0.03	0.0
Diesel long bulk without EGR/SCR		0.12	0.067	0.001		0.03	
Diesel short container with EGR/SCR		0.18	0.087	0.001		0.07	
Diesel short container without EGR/SCR		0.38	0.087	0.001		0.07	
Diesel short bulk with EGR/SCR		0.12	0.084	0.001		0.05	
Diesel short bulk without EGR/SCR		0.25	0.084	0.001		0.05	

J.2.3 IWT

Table 133 - Synthesis of marginal external costs 2016 for EU28 - IWT (in €-cent/tkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
CEMT II bulk - CCR-0		3.36	0.34			0.15	
CEMT II bulk - CCR-1		2.82	0.34			0.15	
CEMT II bulk - CCR-2		1.82	0.34			0.15	
CEMT II bulk - Average		3.25	0.34			0.15	
CEMT II container - CCR-0		2.14	0.21			0.09	
CEMT II container - CCR-1		1.79	0.21			0.09	
CEMT II container - CCR-2		1.15	0.21			0.09	
CEMT II container - Average		2.07	0.21			0.09	
CEMT IV bulk - CCR-0		2.00	0.20			0.09	
CEMT IV bulk - CCR-1		1.67	0.20			0.09	
CEMT IV bulk - CCR-2		1.08	0.20			0.09	
CEMT IV bulk - Average		1.84	0.20			0.09	
CEMT Va bulk - CCR-0	**0.1**	1.82	0.18	n/a	n/a	0.08	0.0
CEMT Va bulk - CCR-1		1.53	0.18			0.08	
CEMT Va bulk - CCR-2		0.99	0.18			0.07	
CEMT Va bulk - Average		1.53	0.18			0.07	
CEMT Va container - CCR-0		2.06	0.21			0.09	
CEMT Va container - CCR-1		1.73	0.21			0.09	
CEMT Va container - CCR-2		1.12	0.21			0.09	
CEMT Va container - Average		1.74	0.21			0.09	
Pushed convoy bulk - CCR-0		1.48	0.15			0.06	
Pushed convoy bulk - CCR-1		1.24	0.15			0.06	
Pushed convoy bulk - CCR-2		0.80	0.15			0.06	
Pushed convoy bulk - Average		0.89	0.15			0.06	

J.2.4 Maritime

Table 134 - Synthesis of marginal external costs 2016 for EU28 - maritime transport (in €-cent/pkm (ferry) and €-cent/tkm (vessels))

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Ferry (RoPax) - Tier 0		24.62	5.53			2.09	
Ferry (RoPax) - Tier 1		22.23	5.53			2.09	
Ferry (RoPax) - Tier 2		20.77	5.53			2.09	
Small container vessel-Tier 0		0.51	0.19			0.07	
Small container vessel-Tier 1		0.51	0.19			0.07	
Small container vessel-Tier 2		0.29	0.19			0.07	
Large container vessel-Tier 0		0.25	0.08			0.03	
Large container vessel-Tier 1	n/a	0.25	0.08	n/a	n/a	0.03	n/a
Large container vessel-Tier 2		0.15	0.08			0.03	
Small bulk vessel - Tier 0		0.33	0.11			0.04	
Small bulk vessel - Tier 1		0.33	0.11			0.04	
Small bulk vessel - Tier 2		0.19	0.11			0.04	
Large bulk vessel - Tier 0		0.12	0.04			0.01	
Large bulk vessel - Tier 1		0.11	0.04			0.01	
Large bulk vessel - Tier 2		0.07	0.04			0.01	

J.2.5 Aviation

Table 135 – Synthesis of marginal external costs 2016 for EU28 – aviation (in €-cent/pkm)

Reference vehicle	Accident	Air pollution	Climate Change	Noise	Congestion	WTT	Habitat
Bombardier CRJ900	0.14	0.28	2.84	0.05	n/a	1.3	0.0
Embraer 170 (ERJ-170-100)		0.30	3.44			1.4	
Airbus A320-232	0.03	0.07	1.53			0.6	0.0
Boeing 737-700		0.11	2.18			0.8	
Airbus A340-300	0.03	0.03	1.36			0.8	0.0
Boeing 777-300 ER		0.04	1.54			0.9	

J.3 Marginal air pollution costs for reference vehicles

Table 136 – Marginal air pollution costs (averages for metropolitan, urban and rural regions)

Vehicle category	Fuel type	Fuel efficiency (average real-world CO_2 emissions)	COPERT category	Motor-ways	Urban roads	Other roads	Average all roads
Passenger transport (€-cent per pkm)							
Passenger car	Petrol	2016 fuel efficient car: 141 g/km	Petrol medium Euro 6	0.08	0.14	0.09	0.10
		2016 fuel inefficient car: 256 g/km	Petrol medium Euro 6	0.08	0.14	0.09	0.10
		2000 fuel efficient car: 176 g/km	Petrol medium Euro 3	0.12	0.19	0.12	0.14
		2000 fuel inefficient car: 243 g/km	Petrol medium Euro 3	0.12	0.19	0.12	0.14
	Diesel	2016 fuel efficient car: 126 g/km	Diesel medium Euro 6	0.47	0.86	0.49	0.61
		2016 fuel inefficient car: 169 g/km	Diesel medium Euro 6	0.47	0.86	0.49	0.61
		2000 fuel efficient car: 147 g/km	Diesel medium Euro 3	0.97	1.90	1.19	1.35
		2000 fuel inefficient car: 192 g/km	Diesel medium Euro 3	0.97	1.90	1.19	1.35
	LPG	169 g/km	Petrol medium Euro 6	0.08	0.15	0.08	0.10
	CNG	136 g/km	Petrol medium Euro 6	0.08	0.14	0.08	0.10
	Full electric	0 g/km	Euro 6	0.06	0.05	0.05	0.05
	PHEV - petrol	133 g/km	Petrol medium Euro 6	0.08	0.06	0.06	0.07
Motorcycle	Petrol	Fuel efficient motorcycle: 100 g/km	Euro 3	0.29	0.32	0.26	0.29
		Fuel inefficient motorcycle: 128 g/km	Euro 3	0.29	0.32	0.26	0.29
Moped	Petrol	70 g/km	Moped 4 stroke	0.53	1.20	0.86	0.86
Motorcycle	Electric	0 g/km		0.02	0.02	0.02	0.02
Bus (18 t)	Diesel	Fuel efficient bus: 954 g/km		0.02	0.12	0.04	0.06

Vehicle category	Fuel type	Fuel efficiency (average real-world CO_2 emissions)	COPERT category	Motor-ways	Urban roads	Other roads	Average all roads
		Fuel inefficient bus: 1,155 g/km		0.41	1.93	0.73	1.02
	CNG	1,007 g/km	Euro 6	0.15	0.53	0.23	0.31
	Electric	0 g/km		0.01	0.04	0.02	0.02
Coach	Diesel	Fuel efficient coach: 583 g/km		0.02	0.21	0.05	0.10
		Fuel inefficient coach: 742 g/km		0.50	2.67	0.88	1.35
LCV (€-cent per vkm)							
LCV	Petrol	2016 fuel efficient LCV: 137 g/km	Euro 6 petrol	0.14	0.16	0.14	0.15
		2016 fuel inefficient LCV: 233 g/km	Euro 6 petrol	0.14	0.16	0.14	0.15
		2000 fuel efficient LCV: 216 g/km	Euro 3 petrol	0.25	0.33	0.24	0.27
		2000 fuel inefficient LCV: 286 g/km	Euro 3 petrol	0.25	0.33	0.24	0.27
	Diesel	2016 fuel efficient LCV: 135 g/km	Euro 6 diesel	1.94	2.19	1.68	1.94
		2016 fuel inefficient LCV: 173 g/km	Euro 6 diesel	1.94	2.19	1.68	1.94
		2000 fuel efficient LCV: 188 g/km	Euro 3 diesel	2.26	4.66	2.57	3.16
		2000 fuel inefficient LCV: 245 g/km	Euro 3 diesel	2.26	4.66	2.57	3.16
	Electric	full electric 0 g/km		0.10	0.08	0.07	0.08
Freight transport (€-cent per tkm)							
HGV 3.5 t-7.5 t	Diesel	Fuel efficient HGV: 370 g/km		0.26	1.55	0.42	0.74
		Fuel inefficient HGV: 450 g/km		4.54	11.65	6.32	7.50
HGV 7.5 t-16 t	Diesel	Fuel efficient HGV: 596 g/km		0.08	0.38	0.12	0.19
		Fuel inefficient HGVs: 716 g/km		1.38	4.46	2.17	2.67
HGV 16 t-32 t	Diesel	Fuel efficient HGV: 716 g/km		0.03	0.18	0.05	0.09
		Fuel inefficient HGVs: 875 g/km		0.67	2.45	1.13	1.42
HGV > 32 t (truck trailer)	Diesel	Fuel efficient HGV: 848 g/km		0.02	0.12	0.04	0.06
		Fuel inefficient HGVs: 1,033 g/km		0.54	2.07	0.92	1.18
	LNG	900 g/km		0.02	0.09	0.03	0.04

J.4 Marginal climate change costs for reference vehicles

Table 137 – Marginal climate change costs

Vehicle category	Fuel type	Fuel efficiency (average type approval CO_2 emissions)	Motor-ways	Urban roads	Other roads	Average all roads
Passenger transport (€-cent per pkm)						
Passenger car	Petrol	2016 fuel efficient car: 99 g/km	0.87	1.01	0.80	0.90
		2016 fuel inefficient car: 180 g/km	1.58	1.84	1.45	1.63
		2000 fuel efficient car: 161 g/km	1.09	1.28	0.98	1.12
		2000 fuel inefficient car: 233 g/km	1.51	1.77	1.35	1.54
	Diesel	2016 fuel efficient car: 89 g/km	0.81	0.89	0.70	0.80
		2016 fuel inefficient car: 119 g/km	1.08	1.20	0.94	1.07
		2000 fuel efficient car: 135 g/km	0.94	1.04	0.82	0.93
		2000 fuel inefficient car: 176 g/km	1.23	1.36	1.07	1.22
	LPG	119 g/km	0.77	0.84	0.66	0.76
	CNG	196 g/km	1.26	1.39	1.08	1.25
	Full electric	0 g/km	0.00	0.00	0.00	0.00
	PHEV - petrol	39 g/km	0.29	0.22	0.23	0.25
Motorcycle	Petrol	Fuel efficient motorcycle: 100 g/km	1.11	0.92	0.82	0.95
		Fuel inefficient motorcycle: 128 g/km	1.34	1.27	1.05	1.22
Moped	Petrol	46 g/km	0.44	0.44	0.44	0.44
Motorcycle	Electric	0 g/km	0.00	0.00	0.00	0.00
Bus (18 t)	Diesel	Fuel efficient bus: 954 g/km	0.46	0.76	0.48	0.57
		Fuel inefficient bus: 1,155 g/km	0.54	0.93	0.58	0.68
	CNG	1,007 g/km	0.06	0.06	0.06	0.06
	Electric	0 g/km	0.00	0.00	0.00	0.00
Coach	Diesel	Fuel efficient coach: 583 g/km	0.23	0.45	0.25	0.31
		Fuel inefficient coach: 742 g/km	0.27	0.60	0.31	0.39
LCV (€-cent per vkm)						
LCV	Petrol	2016 fuel efficient LCV: 105 g/km	1.28	1.65	1.18	1.37
		2016 fuel inefficient LCV: 179 g/km	2.18	2.80	2.01	2.33
		2000 fuel efficient LCV: 198 g/km	1.94	2.82	1.71	2.16
		2000 fuel inefficient LCV: 262 g/km	2.57	3.74	2.27	2.86
	Diesel	2016 fuel efficient LCV: 104 g/km	1.39	1.44	1.22	1.35
		2016 fuel inefficient LCV: 133 g/km	1.78	1.85	1.56	1.73
		2000 fuel efficient LCV: 172 g/km	2.18	2.00	1.46	1.88

Vehicle category	Fuel type	Fuel efficiency (average type approval CO_2 emissions)	Motor-ways	Urban roads	Other roads	Average all roads
		2000 fuel inefficient LCV: 225 g/km	2.84	2.61	1.90	2.45
	Electric	full electric 0 g/km	0.00	0.00	0.00	0.00
Freigh transport (€-cent per tkm)						
HGV 3.5 t-7.5 t	Diesel	Fuel efficient HGV: 370 g/km	4.49	4.49	4.49	4.49
		Fuel inefficient HGV: 450 g/km	5.15	6.25	4.97	5.46
HGV 7.5 t-16 t	Diesel	Fuel efficient HGV: 596 g/km	1.36	1.84	1.42	1.54
		Fuel inefficient HGVs: 716 g/km	1.61	2.30	1.62	1.85
HGV 16 t-32 t	Diesel	Fuel efficient HGV: 716 g/km	0.49	0.78	0.54	0.60
		Fuel inefficient HGVs: 875 g/km	0.58	0.99	0.64	0.74
HGV > 32 t (truck trailer)	Diesel	Fuel efficient HGV: 848 g/km	0.41	0.66	0.45	0.51
		Fuel inefficient HGVs: 1,033 g/km	0.49	0.83	0.53	0.62
	LNG	900 g/km	0.42	0.72	0.47	0.54

J.5 Marginal well-to-tank costs for reference vehicles

Table 138 - Marginal well-to-tank costs

Vehicle category	Fuel type	Fuel efficiency (average real-world CO_2 emissions in g/km)	Motor-ways	Urban roads	Other roads	Average all roads
Passenger transport (€-cent per pkm)						
Passenger car	Petrol	2016 fuel efficient car: 99 g/km	0.33	0.38	0.30	0.34
		2016 fuel inefficient car: 180 g/km	0.60	0.69	0.55	0.61
		2000 fuel efficient car: 161 g/km	0.41	0.48	0.37	0.42
		2000 fuel inefficient car: 233 g/km	0.57	0.67	0.51	0.58
	Diesel	2016 fuel efficient car: 89 g/km	0.19	0.21	0.16	0.19
		2016 fuel inefficient car: 119 g/km	0.25	0.28	0.22	0.25
		2000 fuel efficient car: 135 g/km	0.22	0.24	0.19	0.22
		2000 fuel inefficient car: 176 g/km	0.29	0.32	0.25	0.28
	LPG	119 g/km	0.16	0.18	0.14	0.16
	CNG	196 g/km	0.27	0.30	0.23	0.27
	Full electric	0 g/km	0.84	0.84	0.84	0.84
	PHEV - petrol	39 g/km	0.10	0.08	0.08	0.09
Motorcycle	Petrol	Fuel efficient motorcycle: 100 g/km	0.42	0.35	0.31	0.36
		Fuel inefficient motorcycle: 128 g/km	0.51	0.48	0.40	0.46
Moped	Petrol	46 g/km	0.17	0.17	0.17	0.17
Motorcycle	Electric	0 g/vkm	0.10	0.10	0.10	0.10
Bus (18 t)	Diesel	Fuel efficient bus: 954 g/km	0.11	0.18	0.11	0.13
		Fuel inefficient bus: 1,155 g/km	0.13	0.20	0.13	0.15

Vehicle category	Fuel type	Fuel efficiency (average real-world CO_2 emissions in g/km)	Motor-ways	Urban roads	Other roads	Average all roads
	CNG	1,007 g/km	0.01	0.01	0.01	0.01
	Electric	0 g/km	0.63	0.63	0.63	0.63
Coach	Diesel	Fuel efficient coach: 583 g/km	0.07	0.13	0.08	0.09
		Fuel inefficient coach: 742 g/km	0.08	0.16	0.09	0.11
LCV (€-cent per vkm)						
LCV	Petrol	2016 fuel efficient LCV: 105 g/km	0.48	0.62	0.45	0.52
		2016 fuel inefficient LCV: 179 g/km	0.82	1.06	0.76	0.88
		2000 fuel efficient LCV: 198 g/km	0.73	1.06	0.65	0.81
		2000 fuel inefficient LCV: 262 g/km	0.97	1.41	0.86	1.08
	Diesel	2016 fuel efficient LCV: 104 g/km	0.36	0.37	0.31	0.35
		2016 fuel inefficient LCV: 133 g/km	0.46	0.48	0.40	0.45
		2000 fuel efficient LCV: 172 g/km	0.56	0.52	0.38	0.49
		2000 fuel inefficient LCV: 225 g/km	0.73	0.67	0.49	0.63
	Electric	full electric 0 g/km	3.81	3.81	3.81	3.81
Freigh transport (€-cent per tkm)						
HGV 3.5 t-7.5 t	Diesel	Fuel efficient HGV: 370 g/km	1.04	1.00	0.87	0.97
		Fuel inefficient HGV: 450 g/km	1.13	1.18	0.97	1.09
HGV 7.5 t-16 t	Diesel	Fuel efficient HGV: 596 g/km	0.32	0.43	0.33	0.36
		Fuel inefficient HGVs: 716 g/km	0.34	0.45	0.33	0.38
HGV 16 t-32 t	Diesel	Fuel efficient HGV: 716 g/km	0.11	0.18	0.12	0.14
		Fuel inefficient HGVs: 875 g/km	0.12	0.20	0.13	0.15
HGV > 32 t (truck trailer)	Diesel	Fuel efficient HGV: 848 g/km	0.11	0.19	0.13	0.15
		Fuel inefficient HGVs: 1,033 g/km	0.12	0.21	0.13	0.15
	LNG	900 g/km	0.06	0.11	0.07	0.08

K Overview content Excel file

Two Excel annexes are attached to the report.

The file “Complete overview of country data” contains:
- Total and average costs figures per country:
  - for road, rail and IWT;
  - for all external cost categories;
  - total costs figures are expressed in billion €;
  - average figures in €/pkm (passenger transport), €/vkm (all modes), €/tkm (freight transport, except for LCVs).
- Total and average cost figures per (air)port:
  - for aviation and maritime transport;
  - for all relevant external cost categories;
  - total costs figures are expressed in million €;
  - additionally, average figures in €/LTO & €/passenger & €/tonne for aviation and €/port call & €/million tonnes for maritime transport are presented;
- Marginal costs for:
  - Accidents, per country, in vkm/pkm/tkm
  - Congestion, per country, in vkm
- Input values per country:
  - for all external cost categories;
  - the same units and differentiations as for the EU28 figures are applied.
- All tables and figures from the synthesis Chapter (Chapter 11).

The file “Marginal costs air pollution, climate, WTT, noise” contains marginal costs for:
- Noise, for road and rail in the EU28;
- Reference cases for climate change, air pollution and WTT for all modes in the EU28;
- Selected cases for climate change, air pollution and WTT for road transport in the EU28.

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