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List of abbreviations

dB (A)	decibel (A-weighted), a unit of sound pressure level
EEA	European Environment Agency
ESAL	equivalent standard axle load
GHG	greenhouse gases
HGV	heavy goods vehicle (commercial vehicles with maximum weight above 3500 kg)
IPA	impact pathway approach
IWT	inland waterway transport
L_{den}	A-weighted 24-hour equivalent continuous sound level covering day-evening-night periods, with penalties for evening and night-time periods to represent increased annoyance
LCV	Light commercial vehicles (gross vehicle weight under 3500 kg)
LTO	landing and take-off cycle
NMVOC	non-methane volatile organic compounds
NUTS	Nomenclature of Territorial Units for Statistics
pax	persons (passengers) approximately
pkm	passenger-kilometre
PM	particulate matter (pollutant)
PPP	purchasing power parity
tkm	tonne-kilometre
vkm	vehicle-kilometre
VOC	volatile organic compounds
VSL	value of statistical life

List of key project and model acronyms

CAFE	"Clean Air for Europe" Program of the EU
CAFE CBA	Service contract for carrying out cost-benefit analysis of air quality related issues, in particular in the Clean Air for Europe Program, study on behalf of the European Commission: CAFE CBA (2005a)
CATRIN	"Cost Allocation of TRansport INfrastructure cost" – EU FP6 Project, runtime 2007-2009
COMPETE	"Analysis of the contribution of transport policies to the competitiveness of the EU economy and comparison with the United States", study on behalf of DG TREN, 2006
COPERT	A software tool used to calculate air pollutant and greenhouse gas emissions from road transport
DEHM	"Danish Eulerian Hemispheric Model", part of EVA model system
EcoSense	An integrated environmental impact assessment model developed by the Institute for Energy Economics at the University of Stuttgart
EVA	"Economic Valuation of Air Pollution" – an integrated model for air pollution assessment run by Danish Centre for Environment and Energy
EXIOPOL	"A new environmental accounting framework using externality data and input-output tools for policy analysis" – EU FP6 Project, duration 2007-2011
ExternE	"External Costs of Energy" – series of EU projects
GRACE	"Generalisation of Research on Accounts and Cost Estimation", EU FP6 project, runtime 2005-2008
HEATCO	"Developing Harmonised European Approaches for Transport Costing and Project Assessment", EU FP6 project, runtime 2004-2006
HEIMTSA	"Health and Environment Integrated Methodology and Toolbox for Scenario Assessment", EU FP6 project, runtime 2007-2011
IEHIAS	Integrated Environmental Health Impact Assessment System
IMPACT	"Internalisation Measures and Policies for All external Cost of Transport", study on behalf of European Commission, runtime 2007-2008
INTARESE	"Integrated Assessment of Health Risks of Environmental Stressors in Europe": EU FP6 project, runtime 2005-2010
NEEDS	"New Energy Externalities Developments for Sustainability": EU FP6 project, runtime 2004-2008
NPACT	"National Particle Component Toxicity" Initiative, funded by the Health Effects Institute, USA
RAINS	"Regional Air Pollution Information and Simulation", integrated model managed by International Institute for Applied Systems Analysis, Austria
TREMOVE	Policy assessment model and transport and environmental database, owned by the European Commission
UNITE	UNIfication of accounts and marginal costs for Transport Efficiency, EU Fifth Framework Program

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- Johannes Bröcker, Kiel University
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- Daniel Sutter, INFRAS

Introduction

This section has been adapted from the "Summary" chapter of the 2008 Handbook.

Internalisation of transport external costs: policy background

Transport activities give rise to environmental impacts, accidents, congestion, and infrastructure wear and tear. In contrast to the benefits, the costs of these effects of transport are not fully borne by transport users. Without policy intervention, the so called external costs are not taken into account by transport users when they make travel decisions. Transport users are thus faced with incorrect incentives, leading to welfare losses.

The internalisation of external costs means making such effects part of the decision making process of transport users. According to the welfare theory approach, internalisation of external costs through the use of market-based instruments may lead to a more efficient use of infrastructure, reduce the negative side effects of transport activity and improve the fairness between transport users.

Internalising the external costs of transport has been an important issue for transport research and policy development for many years in Europe and worldwide. A substantial number of research projects, including projects supported by the European Commission, suggest that implementing market-based instruments inspired by the economic theoretical concept of marginal social cost pricing could yield considerable benefits. Fair and efficient transport pricing has also been advocated in a number of policy documents issued by the European Commission, notably the 2011 White Paper on Transport.

When amending Directive 1999/62/EC on charging heavy duty vehicles for the use of certain infrastructure in 2006, the EU legislator requested the European Commission to present a general applicable, transparent and comprehensible model for the assessment of all external costs (including those caused by non-road modes). This model was to serve as a basis for future calculations of road user charges.

Handbook on external costs produced in the IMPACT study

In the light of this mandate from the EU legislator, the European Commission commissioned the IMPACT study[1] in order to summarise the existing scientific and practitioner's knowledge. The central aim of the study was to provide a comprehensive overview of approaches for estimating the external costs of transport and to recommend a set of methods and default values for use when conceiving and implementing transport pricing policy and schemes. The study also provided technical support to the Commission services to carry out an impact assessment of strategies to internalise transport external costs.

The Handbook on external costs estimation (Maibach et al., 2008[2]) that was produced in 2008 as an output of the IMPACT study presented the state of the art and best practice on the methodology for different cost categories. It covered all environmental, accident and congestion costs and considered all transport modes. The focus was on the marginal external costs of transport activity as a basis for the definition of internalisation policies such as efficient pricing schemes. The Handbook does not include information on the existing taxes and charges and does not include information on infrastructure costs.

The 2008 Handbook was based on the existing (until 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.

Update of the Handbook on external costs

The 2008 Handbook proved to be an important source of input data and unit cost values for policy analysis, research projects and academic papers in Europe. In order to maintain this strong standing,

[1] http://www.cedelft.eu/publicatie/deliverables_of_impact_(internalisation_measures_and_policies_for_all_external_cost_of_transport)/702?PHPSESSID=c378bb001713d5baca60a6bb6979cc0d
[2] http://ec.europa.eu/transport/themes/sustainable/internalisation_en.htm

this revised Handbook aims to update the 2008 Handbook with new developments in research and policy.

This updated Handbook continues to present the state of the art and best practice on external cost estimation. Accordingly, the most recent information for the following impact categories has been gathered:

1. Congestion;
2. Accidents;
3. Noise;
4. Air pollution;
5. Climate change;
6. Other environmental impacts (costs of up- and downstream processes);
7. Infrastructure wear and tear for road and rail.

Most important in this context is the road transport sector, due to the fact that road transport is responsible for the majority of external costs.

The illustrative values and bandwidths presented in the Handbook main text are at the EU-level. Supplementary tables provide unit values for Member States.

The updated Handbook provides for each cost category:

- An overview of the latest methods for calculating external costs, their advantages and limitations;
- Highlights on any differences in approach between the updated Handbook and the original 2008 Handbook;
- Recommended approach for calculating external costs;
- Updated recommendations for input values; and
- Updated recommended unit (marginal cost) values.

Every chapter on individual cost categories is structured in a similar way by first providing a discussion of the methodology for the given cost category, then providing updates for critical parameters used in the calculations, and finally updating the unit cost values for road transport and for other modes.

The update is based on a comprehensive literature review. In recent years, progress has been achieved in several areas relevant for external cost estimation:

- Large new databases on noise, accidents and emission factors,
- New and updated models,
- Updated estimates of important input parameters,
- Research identifying additional health effects,
- Case studies and marginal cost calculations.

All of these sources have been used to provide a comprehensive update of the methodology and of the recommended unit costs.

Aim and contents

The Handbook provides information on how to generate external cost values for different external cost categories, as a basis for the definition of internalisation policies such as efficient pricing schemes. This information will be provided at three levels:

Methodological level: What are external costs? What methods can be used to produce external cost figures, in general and for specific external cost categories? How can the results be used for internalisation purposes?

Input values: Which input values (especially in monetary terms, such as the (economic) value of one life year lost, etc.) can be recommended to estimate external costs in the transport sector?

Output values: Which default external costs estimates for different transport modes (if meaningful, unit costs for different traffic situations) can be recommended?

The Handbook follows these three levels, compiling and evaluating the existing scientific and expert work on external cost estimation. The Handbook aims to provide the state of the art and best practice on external cost estimation for policy makers. It considers all transport modes and the work carried out at both the EU and national levels.

Methods for estimating external costs

Although the estimation of external costs has to consider several uncertainties, there is a wide consensus on the major methodological issues. The best practice estimation of congestion costs is based on speed-flow relations, value of time and demand elasticities. For air pollution and noise costs, the impact pathway (or damage cost) approach is broadly acknowledged as the preferred methodology. The valuation of the respective health effects is based on the willingness to pay concept. Marginal accident cost can be estimated by the risk elasticity approach, using values of statistical life. Given long-term reduction targets for GHG emissions, the abatement cost approach (in contrast to the damage cost approach used for other environmental impacts) is the best practice for estimating climate cost. Other external costs exist, e.g. costs related to energy dependency, but there is for the time being no scientific consensus on the methods to value them. In those cases where there is no real scientific consensus on methodology, the different approaches are presented.

Available input values

The external costs of transport activities depend strongly on parameters like location (urban, interurban), time of day (peak, off-peak, night-time) as well as on vehicle characteristics (e.g. EURO standards for pollutant emissions). Within the same Member State, the external cost of one lorry kilometre in urban areas during peak hours can be more than five times higher than the external cost of an interurban kilometre by the same vehicle at off-peak time.

The Handbook provides typical European and Member State input values, based on a comprehensive literature assessment. These input values can be used to produce own output values, with a high level of accuracy. Alternatively, the output values provided for each cost category can be used directly, considering the value transfer approach proposed. These values have lower accuracy, but still provide reliable bandwidths and could be used for policy purposes.

The unit values for input figures are presented in monetary terms related to the specific value, such as Euro per hour, per accident, per unit of emission, per life year lost, etc.

Output values (unit cost values)

The output figures are shown for a common base year (the year 2010) in order to increase comparability. The bandwidths shown represent, in general, the influence of different cost drivers and uncertainties in the cost drivers.

The output values are presented in a form which can be translated for the purpose of internalisation. The main unit is cost per vkm, as a basis for infrastructure pricing. For external costs that are strongly related to fuel consumption, output values expressed in Euro per litre of fuel are also presented. In order to compare different modes, a calculation of cost per passenger or per tonne kilometre has been carried out. Where relevant and useful, other output unit values are shown.

The figures presented are in general representative for the average EU level. In the absence of country-specific values, the suggested value transfer approach based on these average values can be used.

Guidance for practical use

For retrieving cost estimates for specific countries and traffic situations, this Handbook includes guidelines at three different levels: methodology, input values and output values. The accuracy of the values heavily depends on the level chosen:

- First level: Most accurate is the use of the methodology proposed in order to produce own differentiated figures, based on own valuation inputs and own disaggregated data. Even more differentiated approaches than those proposed (e.g. valid for specific countries and traffic situations) can be applied. This level requires availability of evaluation models and of own estimates of the key input parameters.
- Second level: If a transfer of existing values to specific areas and traffic situations is sufficient, the input values shown in this Handbook can be used to produce own output values, based on specific data.
- Third level: For rough and ready estimations with limited resources, the output values provided for each cost category can be used directly, considering the value transfer approach properly. Country-specific values for air pollution costs (road and rail), road congestion costs, road infrastructure costs and noise costs (road and rail) are provided in Excel tables as Annexes to this report.

Overall, the recommendation of the Handbook is to apply the first, most detailed level of analysis for the purpose of the internalisation of external costs, involving gathering case-specific data and calibrating models for the analysis of the specific question at hand. The illustrative ready-to-use unit values provided in the Handbook are meant for the purposes of more aggregate, qualitative analysis in the cases where the accuracy of the results is not the primary goal.

1. External costs of transport: key concepts

This section has been adapted from the "General Methodology" chapter of the 2008 Handbook.

1.1 The concept of external costs

Transport contributes significantly to economic growth and enables a global market. Unfortunately, most forms of transport do not only affect society in a positive way but also give rise to side effects. Road vehicles, for example, contribute to congestion, trains and aircraft to ambient noise levels and ships to air pollution. Such side effects give rise to various resource costs that can be expressed in monetary terms: time costs of delays, health costs caused by air pollution, productivity losses due to lives lost in traffic accidents, abatement costs due to climate impacts of transport, etc.

When side effects of a certain activity impose a cost upon society, economists speak of such a cost as an **external cost**. In contrast to the benefits, the external costs of transport are generally not borne by transport users and hence not taken into account when they make a transport decision.

The **internalisation** of these costs means making such effects part of the decision making process of transport users. This can be done directly through regulation, i.e. command and control measures, or indirectly through providing the right incentives to transport users, namely with **market-based instruments** (e.g. taxes, charges, emission trading, etc.). Combinations of these basic types are possible: for example, existing taxes and charges may be differentiated, e.g. by the EURO emission classes of vehicles.

Internalisation of external costs through the use of market-based instruments is generally regarded as an efficient way to limit the negative side effects of transport. It requires detailed and reliable estimation of external costs, which is the subject of this Handbook.

In order to define external costs properly it is important to distinguish between:

- **Social costs** reflecting all costs occurring due to the provision and use of transport infrastructure, such as wear and tear costs of infrastructure, capital costs, congestion costs, accident costs, environmental costs.
- **Private (or internal costs)**, directly borne by the transport user, such as wear and tear and energy cost of vehicle use, own time costs, transport fares and transport taxes and charges.

External costs refer to the difference between social costs and private costs. But in order to produce quantitative values, the definition has to be more precise. Based on the economic welfare theory, transport users should pay all marginal social costs which are occurring due to a transport activity. Considering the private marginal costs (such as wear and tear costs of the vehicle and personal costs for the driver), optimal infrastructure charges should reflect the marginal external costs of using an infrastructure. These costs include wear and tear costs for the use of infrastructure, congestion costs, accident costs and environmental costs.

In the short run, these costs are linked to constant infrastructure capacity. Thus, fixed infrastructure costs are not relevant for efficient pricing. In the long run, however, the change of infrastructure capacity due to the construction of additional traffic infrastructure is relevant, too. From an economic viewpoint, an infrastructure project is economically viable, if additional social benefits of a specific project exceed additional social costs.

Whereas the short run marginal costs are relevant for efficient pricing of existing infrastructure, the long run marginal costs also have to consider the financing of infrastructure extensions. The distinction between short and long run marginal costs requires a clear statement on how to treat existing fixed and variable infrastructure costs and related financing schemes such as transport related taxes and charges. Thus, it is useful to separate infrastructure costs, taxes and charges from other external cost components.

Within this Handbook, the focus is on the marginal external costs using transport infrastructure as a basis for applying market-based instruments so that transport prices can be corrected to account for their societal impacts. Different cost categories are covered in Chapters 2-7. Marginal infrastructure costs are addressed in Chapter 8.

1.2 Scope of external costs and level of externality

The following Table 1 provides an overview of the external costs covered in this Handbook.

Table 1: External cost components and level of externality

Cost component	Private and social costs	External part in general	Differences between transport modes
Costs of scarce infrastructure (congestion and scarcity costs)	All costs for traffic users and society (time, reliability, operation, missed economic activities) caused by high traffic densities.	Extra costs imposed on all other users and society exceeding own additional costs.	For non-scheduled transport (road sector), the external cost component is the difference between marginal cost and average cost based on a congestion cost function. For scheduled transport services (rail, air), the external cost component is the difference between the willingness to pay for scarce access slots and the existing access slot charge.
Accident costs	All direct and indirect costs of an accident (material costs, medical costs, production losses, suffering and grief caused by fatalities).	Part of social costs which is not considered in own and collective risk anticipation and not covered by (third party) insurance.	There is a debate on the level of collective risk anticipation in individual transport; are the costs of a self-induced accident a matter of (proper) individual risk anticipation or a collective matter? Besides, there are different levels of liability between private insurance schemes (private road transport) and insurance schemes for transport operators (rail, air, waterborne).
Environmental costs	All damages of environmental nuisances (health costs, material damages, biosphere damages, long term risks).	Part of social costs which is not considered (paid for).	Depending on legislation, the level of environmental taxation or liability to realise avoidance measures differs between modes.

Source: 2008 Handbook

In order to define the level of externality for these cost components properly, the following arguments have to be considered.

- Parts of the congestion costs are ‘paid' by the waiting and delay costs of the users; other elements of these costs, namely those imposed on other users, are not. The measurement of the external part has to consider congestion dynamics. Since marginal costs are above-average costs with increasing congestion, the difference between these two levels is considered as the external cost element, since average costs are paid by the user. Within existing practice, the focus is directly on the external part.
- Parts of the accident costs are paid by third-party insurance, other parts are ‘paid’ by the victim having themselves caused the accident (either through own insurance or through suffering uncompensated damage, etc.). Thus it is very important to consider the total volume of insurance fees related to the transport sector and the damage paid for outside the insurance system (also sometimes called ‘self-insurance’). Within existing practice of cost estimation, the focus is directly on the external part. Translating the external part into internalisation measures, the national liability systems have to be considered.
- Parts of environmental costs could be seen as already ‘paid’ for, such as through energy taxes or environmental charges (e.g. noise-related charges on airports).

In this context it can be added that accident costs, congestion costs and environmental costs differ significantly with respect to the parts of society affected: While external accident costs are typically imposed on readily-identifiable individuals (victims of an accident and their families), congestion costs are imposed on the collective of transport users caught in a traffic jam or having been crowded out. This holds true even more for environmental externalities that are imposed on society at large (even affecting different generations). Especially the fact that accident costs are imposed on readily-identifiable individuals may ask for recommending a more tailor-made (individual) approach of internalisation.

Furthermore, having the aim of optimal infrastructure charging in mind, it is important to stress the difference between average and marginal external costs. As mentioned above, economic theory suggests that the marginal social costs should be the basis for efficient charging, as it would lead to a socially optimal equilibrium. However, the sum of charges based on marginal social cost pricing does not necessarily correspond to the total costs imposed by the users on the society.

1.3 Best practice methodologies

1.3.1 Valuation approaches

Individual preferences are the most important indicator to value costs imposed on society (externalities). The preferred solution is to estimate damage costs. For some externalities, like long term risks, collective preferences also have to be considered. In order to value individual preferences, the following approaches are relevant:

- The willingness to pay (WTP) for an improvement.
- The willingness to accept (WTA) a compensation for non-improvement.

Several methods can be used to approximate resource costs directly. They can be measured by the market price of a certain effect (losses, compensation). In order to get the real costs, taxes and subsidies have to be extracted using factor costs. If resource costs are not available, hypothetical market situations have to be constructed. Several methods can be used; all of them have strengths and weaknesses: The stated preference (SP) method using a contingent valuation approach directly measures the WTP, but depends very much on the survey design and the level of information, and suffers from the fact that it involves hypothetical expenditures only. Also indirect methods like revealed preferences (RP; e.g. hedonic pricing where house price differentials can be used to estimate costs of noise) are therefore viable. For several environmental costs (e.g. relevant for long term risks and habitat losses), more differentiated approaches are necessary, since the stated preference approach is only useful for the valuation of individual key values such as the value of a human life.

A major recommended approach for evaluating environmental impacts is the **impact pathway approach** (such as used by the ExternE method specifically developed for air pollution). This approach follows the dose-response function considering several impact patterns on human health and nature. Sometimes the lack of certain information (or high uncertainty) on the dose-response function renders it necessary to combine this approach with a standard price approach, as an alternative for the model estimation of the damage level. In this case, as a second best approach, the avoidance cost approach (cost to avoid a certain level of pollution) can be used.

Table 2 summarises the best practice approaches for different cost categories pointing out the sensitive issues.

Table 2: Best practice valuation approaches for most important cost components

Cost component	Best practice approach
Costs of scarce infrastructure	WTP[a] for the estimation of the value of time (based on stated preference approaches). Alternatively: WTA[b]. WTP for scarce access slots (based on SP[c] with real or artificial approaches). Alternatively: WTA.
Accident costs	Resource costs for valuation of injuries. WTP for the estimation of the value of statistical life, based on SP for the reduction of traffic risks. Alternatively: WTA.
Air pollution costs and human health	Impact pathway approach using resource cost and WTP for human life (life years lost). Alternatively: WTA.
Air pollution and building/material damages	Impact pathway approach using repair costs.
Air pollution and nature	Impact pathway approach using losses (e.g. crop losses at factor costs).
Noise	Annoyance costs: WTP approach based on hedonic pricing (loss of rents – this reflects WTA) or SP for noise reduction. Health costs: impact pathway approach for human health using WTP.
Climate change	Avoidance cost approach based on reduction scenarios of GHG-emissions; alternatively, damage cost approach; shadow prices of an emission trading system.
Nature and Landscape	Compensation cost approach (based on virtual repair costs).

[a] willingness to pay, [b] willingness to accept, [c] stated preference approach

Source: 2008 Handbook

1.3.2 Procedures: Top-down and bottom-up estimation

The estimation of marginal costs is usually based on bottom-up approaches considering specific traffic conditions and referring to case studies. They are more precise and accurate, with potential for differentiation. On the other hand, the estimation approaches are costly and difficult to aggregate (e.g. to define representative average figures for typical transport clusters or national averages).

Alternatively, top-down approaches using average national data are applied. Such approaches are more representative on a general level, allowing also a comparison between modes. On the other hand the cost function has to be simplified and cost allocation to specific traffic situations and the differentiation for vehicle categories is rather rough.

The existing literature for efficient pricing mainly recommends a bottom-up approach following the impact pathway methodology. In practice, however, a mixture of bottom-up and top-down approaches (with representative data) can be observed. Most important is the definition of appropriate clusters with similar cost levels (such as air pollution levels, traffic characteristics and population density).

Table 3 shows the difference between marginal cost (bottom-up) and average cost (top-down).

Table 3: Relation between marginal and average costs and links to internalisation

Cost component	Difference between marginal and average costs	Practical implementation and proposed differentiation
Costs of scarce infrastructure	In congested areas, marginal costs are above average costs. The difference is relevant to define external costs.	Estimation of marginal cost based on speed-flow curves for specific traffic clusters (urban-interurban, peak-off-peak). Top-down approaches are not feasible.
Accident costs	Marginal costs differ individually (for non-scheduled traffic). Clustering of Infrastructure users according to accident risk is possible (and typically applied by insurance companies). Thus, average and marginal costs can be assumed to be similar in each cluster.	Differentiation (cluster of users) according to schemes applied by insurance companies.
Air pollution costs and human health and building/material damages	Linear dose-response function: Marginal costs similar to average costs.	Marginal (averaged) costs per type of vehicle (EURO-class) and traffic and population clusters (urban, interurban).
Air pollution and nature	Linear dose response function: Marginal costs similar to average costs.	Marginal (averaged) costs per type of vehicle (EURO-class) and traffic clusters (urban, interurban).
Noise	Decreasing impact of an additional vehicle with increasing background noise due to logarithmic scale. Marginal costs below average costs.	Marginal (averaged) costs per traffic and population clusters (urban, interurban).
Climate change	Complex cost function. As a simplification: Marginal damage costs similar to average costs (if no major risks included). For avoidance costs, marginal costs are higher than average costs.	Marginal (averaged) costs per type of vehicle and/or fuel.
Nature and landscape	Marginal costs are significantly lower than average costs.	Averaged (or marginal) variable costs per type of Infrastructure.

Source: 2008 Handbook

1.4 Similarities and differences between modes of transport

Existing studies on external costs have mainly concerned road transport. The evidence shows that road transport has by far the largest share in total external costs of transport. In order to cover all transport modes and to transfer (where appropriate) existing knowledge on external cost estimation from one mode to other modes, some similarities and differences between modes have to be considered. Table 4 provides an overview.

Table 4: Most important differences between transport modes

Cost component	Road	Rail	Air	Water
Costs of scarce Infrastructure	Individual transport is causing collective congestion, concentrated on bottlenecks and peak times.	Scheduled transport is causing scarcities (slot allocation) and delays (operative deficits).	See Rail.	If there is no slot allocation in ports/channels, congestion is individual.
Accident costs	Level of externality depends on the treatment of individual self-induced accidents (individual or collective risk) insurance covers compensation of victims (excluding value of life).	Difference between driver (operator) and victims. Insurance is covering parts of compensation of victims (excluding value of life).	See Rail.	See Rail.
Air pollution costs	Close link between population density and damage costs	The use of diesel and electricity should be distinguished.	Air pollution impacts in high altitude have to be considered.	Air pollutants in harbour areas are complicated to allocate.
Noise	Close link between population density and damage costs	Rail noise is usually considered as less annoying than other modes (rail bonus). But this depends on the time of day and the frequency of trains.	Airport noise is more complex than other modes (depending on movements and noise max. level and time of day).	No major issue.
Climate change	All GHGs relevant.	All GHGs relevant, considering use of diesel and electricity production.	All GHGs relevant (Air pollution impacts in high altitude to be considered).	All GHGs relevant.
Nature and landscape	Differentiation between historic network and motorways extension.	Differentiation between historic network and extension of high speed network.	No major issues.	Relevant for new inland waterways (channels). External costs of single accidents may be extremely high (e.g. oil spills).

Source: 2008 Handbook

1.5 Overview

The most important recommendations can be summarised as follows:

- Costs of scarce infrastructure (congestion for road, scarcity for other modes), selected parts of accident costs, and environmental costs are treated as the external costs of transport according to the welfare-theory approach.
- The level of externality differs according to cost categories and transport modes. Environmental costs are considered as fully external.
- The values should be based on marginal cost estimation for specific traffic situations and clusters. If an aggregation of figures is difficult and cost functions are complex, top-down approaches based on national values may be used in addition.
- The valuation methodology should follow the impact pathway approach using willingness to pay or willingness to accept approaches. If the dose-response functions are complex or uncertain, other approaches such as the estimation of avoidance costs can be appropriate (e.g. for climate costs).
- The differences between transport modes are specifically relevant for congestion/scarcity costs and the consideration of the production of electricity for the railways.
- The unit values should be presented considering the main cost drivers. Costs per traffic unit are a common basis. For some externalities however, other cost drivers have to be considered, too.

Table 5 shows the main issues and cost drivers per cost component. The following chapters present the details per cost category.

Table 5: Overview of main issues per cost category

Cost component	Cost elements	Critical valuation issues	Cost function	Data needs	Main cost drivers[3]
Congestion costs (road)	Time and operating costs Additional safety and environmental costs	Speed-flow relations Valuation of economically relevant value of time (reliability)	Increasing marginal cost in relation to traffic amount, depending on time of the day/week/year and region	Speed-flow data Level of traffic and capacity per road segment	Type of Infrastructure Traffic and capacity levels, mainly depending on: – Time of the day – Location – Accidents and constructions
Scarcity costs (scheduled transport)	Delay costs Opportunity costs Loss of time for other traffic users	Valuation approach as such (measurement of opportunity costs, WTP enlargement costs, optimisation model)	Increasing marginal cost in relation to traffic amount, depending on time of the day/week/year and region	Level of traffic, slot capacity per infrastructure segment	Type of infrastructure Traffic and capacity levels, mainly depending on: – Time of the day – Location
Accident costs	Medical costs Production losses Loss of human life	Valuation of human life Externality of self-induced accidents in individual transport Allocation of accidents (causer/victim related)	Only limited correlation between traffic amount and accidents; other factors (such as individual risk factors and type of Infrastructure)	Accident database. Specification of the number of fatalities and heavy/slight injuries very important.	Type of Infrastructure Traffic volume Vehicle speed Driver characteristics (e.g. age, medical conditions, etc.) Others
Air pollution	Health costs Years of human life lost Crop losses Building damages Costs for nature and biosphere	Valuation of life years lost Market prices for crops Valuation of building damages Valuation of long term risks in biosphere	Correlation with traffic amount, level of emission and location	Emission and exposure data (exp. PM, NO_x, SO_2, VOC)	Population and settlement density Sensitivity of area Level of emissions, dep. on: – Type and condition of vehicle – Trip length (cold start emissions) – Type of Infrastructure – Location – Speed characteristics

3 Not all cost drivers will be applicable as a basis for incentives.

Cost component	Cost elements	Critical valuation issues	Cost function	Data needs	Main cost drivers[3]
Noise costs	Annoyance costs Health costs Rent losses	Valuation of health and annoyance impacts	Declining marginal cost curve in relation to traffic amount	Noise exposure data (persons) House price data for applying hedonic pricing methods.	Population and settlement density Day/Night Noise emissions level, depending on: – Type of Infrastructure – Type and condition of vehicle – Vehicle speed characteristics
Climate change	Prevention costs to reduce risk of climate change Damage costs of increasing temperature	Long term risks of climate change Level of damage in high altitudes (aviation)	Proportional to traffic amount and fuel used (marginal cost close to average cost)	Emission levels	Level of emissions, depending on: – Type of vehicle and add. equipment (e.g. air conditioning) – Speed characteristics – Driving style – Fuel use and fuel type
Costs for nature and landscape	Costs to reduce separation effects Compensation costs to ensure biodiversity	Valuation approach as such (replacement versus WTP approach)	Most of the costs are Infrastructure related, and do not vary very much with traffic volumes	GIS information on Infrastructure	Type of Infrastructure Sensitivity of area
Additional environmental cost (water, soil)	Costs to ensure soil and water quality	Valuation approach as such (avoidance versus damage cost approach)	Complex: Increasing marginal cost curve in relation to traffic amount	GIS information Infrastructure, emission levels	Level of emissions Type of Infrastructure
Additional costs in urban areas	Separation costs for pedestrians Costs of scarcity for non-motorised traffic	Valuation approach as such (Avoidance versus WTP approach)	Increasing marginal cost curve in relation to traffic density	Infrastructure data in urban areas (network data, data on slow traffic)	Type of Infrastructure Level of traffic

Source: 2008 Handbook

2. Congestion costs

2.1 Methodological developments and new data sources

2.1.1 The concept of external congestion cost in road traffic

The concept of congestion externalities is easy to understand but difficult to quantify. A user of a road network affects, by his/her decision to use the network for driving from A to B, the utility of all other users who want to use the same network capacity. The utility loss, aggregated over all those other users, is the negative external effect of the respective user's decision to go from A to B. As utility itself cannot sensibly be added up, utility is first translated to monetary terms before aggregation, i.e. the willingness to pay for avoiding the utility loss. Thus, the external effect is measured in terms of a monetary amount per trip.

Principally there are two different interpretations of this definition that are known as the Market Marginal Congestion Cost (MMCC) and the Efficient Marginal Congestion Cost (EMCC). The former is quantified under the assumption that the allocation of flows in the network is a decentralised user equilibrium, where users do not pay for the externalities they cause. The latter is quantified under the assumption that the allocation can be made efficient by forcing all users to pay a congestion charge just equal to the exerted externality. It is recommended that only EMCCs are included in external cost calculations. This is because motivation for making users pay for congestion externalities is to achieve an efficient use of the network. The externality that users should pay for is thus the EMCC, not the MMCC.

There is much confusion among practitioners as well as in some parts of the literature as to whether the external costs just defined can really be regarded as external. It is sometimes argued that road vehicle users exert a negative effect only on road vehicle users, i.e. on themselves, such that the costs are internal to the group of road vehicle users. Hence, as road vehicle users do not affect the utility of non-road vehicle users, they should not be charged for the negative effect just described. This type of argument confuses issues of fairness and of efficiency. The impact of vehicle usage on the speed of other vehicles leads to inefficiency in the use of scarce road capacity, because individual vehicle users neglect this impact in their respective individual decisions. Any negative or positive impact on others that is not compensated by equivalent monetary payments leads to such an inefficiency, irrespective of whether those others belong to the same group. Fairness is a different matter; charges on road usage could be regarded as fair for the totality of road users if these charges, plus other contributions to financing the infrastructure add up to the costs of infrastructure. If congestion charges are introduced in a situation where the infrastructure is already financed by other contributions, it could be regarded as fair to compensate the totality of road users by reducing those other contributions by the revenues from charging. It could also be shown that under certain – though not terribly realistic – conditions optimal charges would just suffice to finance an optimal supply of infrastructure.

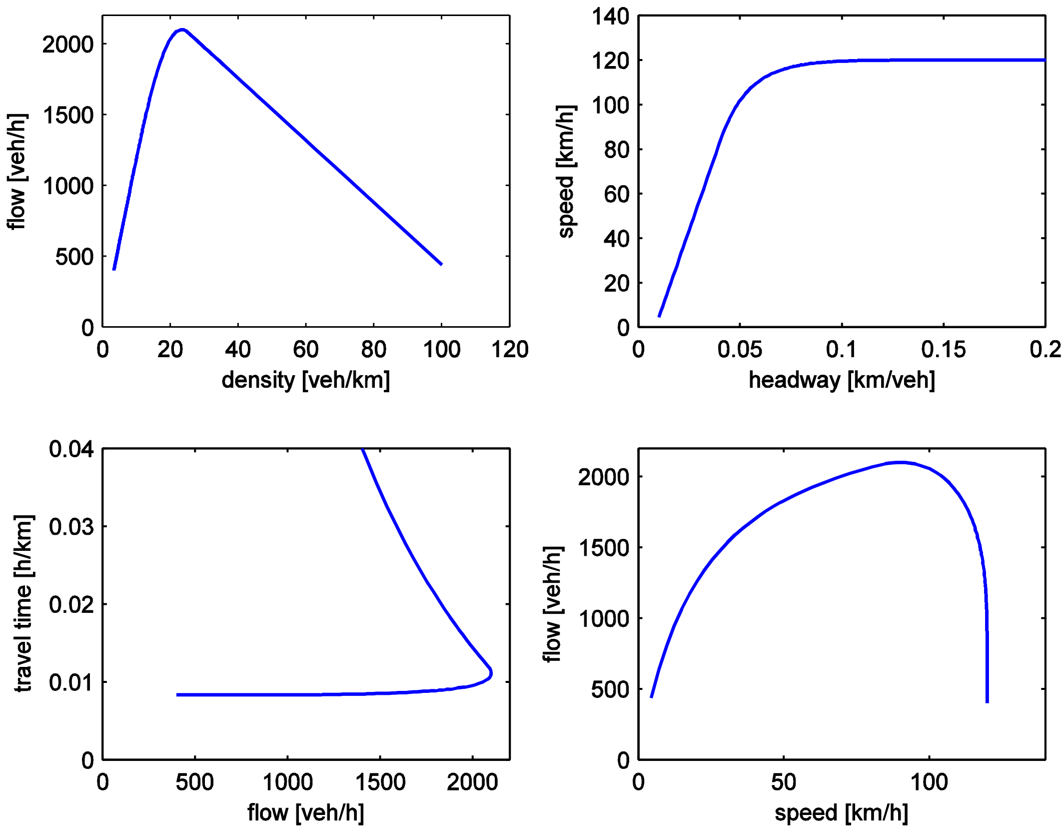
There are two basic models of congestion externalities in the literature: the bottleneck model first proposed by Vickrey (1963), and the link model. The link model appeared for the first time in Pigou (1920). The bottleneck model describes a situation where a group of users want to pass one bottleneck at a desired point in time. The bottleneck's capacity is given by the maximal flow, i.e. the number of vehicles per hour that can pass. Users dislike arriving early or late, after having passed the bottleneck. In equilibrium there is a queue, first growing and then gradually declining, such that all users are equally well off. Some do not wait for long in the queue, but arrive early or late, others arrive just in time but have to wait in the queue for longer periods. An optimal road price replaces the inconvenience of waiting with the inconvenience of paying the price. User's utility remains unchanged by introducing the price, but the revenue is a net gain of the society. Applying this model in practice is difficult because it is dynamic. Though dynamic network assignment models are available in the literature (see e.g. Peeta and Ziliaskopoulos 2001), standard practice in traffic assignment is still based on static peak hour assignment.

There is no doubt, however, that a dynamic approach would be highly desirable for estimating efficient charges. Price differentiation across time, such as different charges for peak and off-peak hours, only very imperfectly takes account of the congestion dynamics because the required time schedule depends on the growth and decline of queues in different parts of the network that have their own respective patterns across time. There is, however, a recent attempt to use the bottleneck model in practice. De Palma and Lindsey (2006) use a dynamic assignment model for calculating efficiency gains of a dynamic charging scheme. Unfortunately, the model does not allow for an explicit incorporation of dynamic charges. The authors therefore approximate a dynamic charging scheme by a simple but intuitive rule, namely by just charging travel time. As travel time depends on both distance and congestion, a charge on travel time turns out to be a fairly good approximation to an efficient dynamic charging scheme. The efficiency gain turns out to be considerable, and clearly much bigger than that of static link charges. The practical usefulness of this approach seems to be questionable, however. Acceptance problems for a scheme that makes users pay for time losses in queues when they are annoyed at getting stuck in a queue anyway are likely impregnable. Another problem is that if paying for travel time, road users are entrapped to drive faster, which would be a non-desirable implication of such a charging scheme. It is recommended to keep the issue of dynamic charging in mind and to support attempts to make dynamic assignment models fit for taking optimal charging schemes on board. An acceptable, practical and easily accessible solution, however, does not yet seem to be available.

The conventional static link model predicts flows along links in the network that depend on link speeds, which in turn depend on how close traffic flows come to the respective link capacities. The conventional congestion model for flows along links starts from the characteristic of a link as described by the so-called fundamental diagram (Figure 1 overleaf). The diagram relates speed along a link to the flow. Alternatively, transformations of these variables are related to each other in a way encompassing the same information. Much effort in the literature over the last decades has gone into specifying functional forms of the diagram and estimating its parameters. For a review and unifying framework see Li (2008). In the analysis included in Annex A1, it is shown that these efforts have little bearing for quantifying the EMCC in practice.

On the contrary, the conclusion is that a useful ad-hoc rule for an EMCC just based on observations of flows or speeds does not exist in the conventional model. The essential information needed, namely the position of the demand curve, is not observable on the road link. It has to be obtained from a network assignment model. It is unlikely that any sensible number on the EMCC along a road could be obtained without calibrating such a model. This is also true because road links in a network interact: what is required to determine the EMCC is not the position of the demand curve under conditions of a decentralised inefficient equilibrium, but under the condition that on all links users are charged in an efficient way.

Figure 1: The Fundamental Diagram of traffic flow



One must go beyond the conventional model, because it is based on a deterministic approach to the relation between speed and flow, while modern traffic flow theory favours a stochastic approach (Treiber and Helbing 1999; Treiber, Kesting, and Helbing 2010; Kerner 2009). This approach emphasises phase transitions between free-flow conditions where cars move along the road at almost full speed, and queues emerging stochastically. Unfortunately, while there is extensive literature on the best fitting speed-flow relations for the deterministic approach, there is no useful literature yet allowing for a calibration of the cost expectation function in the stochastic approach.

2.1.2 Recommended approach for road transport

In the more extensive analysis included in Annex A1 it is concluded that useful estimates of EMCCs cannot be obtained by simple rules of thumb. It is also demonstrated that just observing traffic flows under conditions of decentralised decision making with zero congestion charging does not provide sufficient information for deriving even approximate EMCC estimates. One cannot dispense with producing at least a rough approximation of flows as well as cost expectations in a system equilibrium. There are principally two ways of getting there: a full network-based approach and an aggregate (economic) approach.

A **network-based system equilibrium** takes the most important responses of drivers into account: choice of route, destination (or length of trip), mode and time of the day. This is an undertaking not significantly more complex than estimating a decentralised network-based user equilibrium, which is a standard element of a transport plan evaluation. Two conditions have to be fulfilled to allow for it. First, reasonable estimates of speed-flow relations are needed that can be interpreted as perceived user cost expectations in the sense explained in Annex A1. Speed-flow relations from engineering studies (such as the curves in Figure 1) are of little help in this regard because, for a given road link, they typically do not offer estimates of the per hour probability that the stability of a flow breaks down. They also do not reveal the waiting time that users expect to be stuck in a queue.

The best information currently available (that is useful in this respect) is the bundle of speed-flow relations of the FORGE model used in the National Transport Model of the UK (DfT 2009). These relations consist of either two or three line segments. The first segment shows a slight decline of speed, if the flow starts growing, the other one or two show a steeper decline on congested roads. These curves differ from the static engineering curves in two respects. First, the congestion zone starts at lower flow-to-capacity ratios (2/3 to 3/4), and second, flows are allowed to exceed the capacity, corresponding to the phenomenon already discussed: users getting stuck when the capacity is exceeded do not expect to be stuck forever.

The second condition for producing network-based estimates of EMCCs is the availability of modelling software capable of solving for an optimum in the transport system and capable of reporting user costs as well as their respective first derivatives attained at this optimum. The following software systems were examined for this feature:

- Emme/4 (http://www.inrosoftware.com/en/products/emme/index.php)
- Visum (http://vision-traffic.ptvgroup.com/en-us/products/ptv-visum/) and
- SATURN (http://www.saturnsoftware.co.uk/saturnmanual/).

Both, Emme/4 and Visum provide calculation of a system equilibrium as a built-in feature. Also, both allow for user-supplied cost functions. Thus, cost expectation functions with a better validation can easily be incorporated. In SATURN, the calculation of EMCCs is more involved. One can comfortably evaluate a given charging plan, but for optimal charging one would have to iterate, starting with a suggested plan, obtaining the external costs (which are then not yet efficient), using them for a new plan, and so forth until convergence. Convergence may however be difficult or impossible to achieve this way.

The second option for quantification is a more **aggregated approach**. The UK approach using the FORGE model (DfT, 2005, 2009) is a viable alternative to a full network-based modelling exercise. FORGE defines a travel demand vector whose coordinates quantify demand for road traffic differentiated in several dimensions, namely

- Area,
- Type of region (rural versus urban),
- Trip purpose,
- Type of vehicle,
- Type of road ,
- Congestion band, and
- Time zone of day.

Demand responds to generalised cost composed of time costs and monetary costs. Time costs are derived from the speed-flow relations referred to above. Monetary costs also depend on the speed as obtained from the speed-flow relations. The demand response is described by a rather complex substitution structure, using evidence-based elasticities of substitution and a-priori admitting or excluding certain substitutions depending on plausibility.

The approach calculates EMCCs in an iterative way, starting from a known benchmark equilibrium. This equilibrium may be the observed situation in a benchmark year that is going to be changed by a demand expansion representing the demand situation of a prediction year. It may also be a decentralised zero-charge equilibrium that is going to be changed by introducing EMCCs. The adjustments of supply and demand are calculated in an iterative way. One goes back and forth between quantities in the respective cells of the demand vector and costs per trip, including charges that are equal to the externality as given in the following equation (see Appendix A1, Equation (2)):

$$E = \varphi f \frac{\mathrm{d}t(f)}{\mathrm{d}f} = -\frac{1}{\varepsilon(f:v)}\frac{\varphi}{v},$$

where E is the EMCC estimate, t is travel time, φ is the average value of time, $\varepsilon(f:v)$ is the elasticity of flow f with respect to speed v.

The outcome is a detailed list of charges differentiated by road type, area and congestion band, as shown in Table 6. An approach to make use of these estimates is developed in the next section.

Table 6: Efficient Marginal Congestion Cost estimates for cars from the FORGE model, pence per vkm, 2010

Congestion band	London			Inner and Outer Conurbations			Other Urban		Rural			Weighted Average
	Motorways	A roads	Other Rds	Motorways	A roads	Other Rds	A roads	Other Rds	Motorways	A roads	Other Rds	
1	0.0	1.4	12.8	0.0	0.9	2.4	0.6	2.4	0.0	0.4	0.2	1.2
2	0.0	4.5	26.4	0.0	3.1	9.5	1.9	9.0	0.0	1.3	1.5	2.9
3	0.0	20.3	54.6	0.6	25.6	21.2	11.0	19.4	1.0	3.4	7.8	10.2
4	14.1	135.8	150.7	25.8	136.2	153.7	46.9	134.4	18.7	50.6	40.5	90.3
5	0.0	265.8	205.8	59.3	174.7	233.8	73.1	222.2	79.5	120.2	134.2	159.9
Average	0.1	69.2	48.4	2.9	35.2	24.5	13.6	11.2	1.1	2.3	2.8	11.8

Source: DfT (2012)

2.2 Updated unit values for congestion costs

2.2.1 Road congestion

The update of the unit values for congestion costs is based on the aggregated approach of the FORGE model used in the National Transport Model of the UK (DfT, 2009). A very useful feature of the estimates is the differentiation of several congestion bands.

The congestion bands reflect the volume to capacity ratio of a traffic link. The volume (v) is the actual traffic flow and the capacity (c) is the theoretical maximum traffic flow. These can be expressed in terms of vehicles (or PCU (passenger car units)) per time period per road (or lane) length. Table 7 shows how the congestion bands relate to the v/c ratios.

Table 7: Congestion band definition in the FORGE model

Congestion band	Volume / Capacity
1 : free flow	v/c < 0.25
2	0.25 < v/c < 0.5
3	0.5 < v/c < 0.75
4 : near capacity	0.75 < v/c < 1
5 : over capacity	v/c > 1

Source: DfT (2012)

Further, the FORGE model distinguishes between several types of areas and roads. The results for London will not be considered, as they can be regarded as too specific. Instead, the results for “conurbations” (other large cities) are used as a proxy for typical metropolitan areas.

Regarding the road types, the FORGE model distinguishes between motorways, “A roads” (UK trunk and principal roads with 1 and 2 lanes) and other roads. “A roads” will be used as a proxy for other major roads.

A strong feature of the UK National Transport Model is that it includes data on the shares of traffic in each of the congestion bands on each type of road. This allows the calculation of the averages across all congestion bands or all road and area types, as in Table 6. For the EU, no such information is readily available, and therefore, it is not possible to calculate such averages. However, for peak hours the higher congestion bands are most representative of the external congestion costs.

The information on the traffic shares also gives an indication of the reliability of the marginal cost estimates in FORGE. The estimates are based on speed-flow relations that are specific to area and road type. These speed-flow relations are based on national speed survey data and thus suffer from high uncertainty if the sample size is small. This seems to be the case especially with respect to the estimates for rural areas. The proportion of traffic observed on important roads in rural areas under high congestion is very small (lower than 0.05%). Therefore, one has to treat the corresponding values in Table 6 with caution.

Comparing the marginal cost estimates on motorways and A roads in congestion bands 4 and 5 between urban and rural areas, one can notice that the values for rural areas are higher, which is not plausible. Given the low traffic share, it is clear that the estimates for rural areas are less reliable. Therefore, a correction to the original FORGE results in rural areas is introduced. The rate of increase of marginal costs for higher congestion bands on rural motorways is transferred from the results for urban areas. For A roads, the rate of increase from other rural roads is used.

In order to transfer the estimates for passenger cars to other vehicle types, the Passenger Car Unit (PCU) equivalent factors are applied. The factors from the FORGE model are listed in Table 8. The capacity flow assumptions in the model are in the order of 2000 PCU/lane-km for motorways and 800-1000 PCU/lane-km for other roads.

Table 8: Passenger Car Unit equivalence factors in the FORGE model

Vehicle Type	PCU Factor
Car	1.0
Light goods vehicle	1.0
Rigid HGV	1.9
Articulated HGV	2.9
Public service vehicle (e.g. bus)	2.5

Source: DfT (2012)

Taking all these assumption into account, the illustrative unit values for road congestion costs are reported in Table 9. The region definitions are the same as in the FORGE model and take only population numbers into account. Metropolitan area corresponds to cities with the population above 250 thousand people; urban area includes settlements with a population of more than 10 thousand people. All other areas are considered rural.

Table 9: Efficient Marginal Congestion Costs, €ct per vkm, 2010, EU average*

Vehicle	Region	Road type	Free flow (€ct/vkm)	Near capacity (€ct/vkm)	Over capacity (€ct/vkm)
Car	Metropolitan	Motorway	0.0	26.8	61.5
		Main roads	0.9	141.3	181.3
		Other roads	2.5	159.5	242.6
	Urban	Main roads	0.6	48.7	75.8
		Other roads	2.5	139.4	230.5
	Rural	Motorway	0.0	13.4	30.8
		Main roads	0.4	18.3	60.7
		Other roads	0.2	42.0	139.2
Rigid truck	Metropolitan	Motorway	0.0	50.9	116.9
		Main roads	1.8	268.5	344.4
		Other roads	4.7	303.0	460.9
	Urban	Main roads	1.2	92.5	144.1
		Other roads	4.7	264.9	438.0
	Rural	Motorway	0.0	25.4	58.4
		Main roads	0.8	34.8	115.3
		Other roads	0.4	79.8	264.5
Articulated truck	Metropolitan	Motorway	0.0	77.6	178.4
		Main roads	2.7	409.8	525.6
		Other roads	7.2	462.5	703.5
	Urban	Main roads	1.8	141.1	219.9
		Other roads	7.2	404.4	668.6
	Rural	Motorway	0.0	38.8	89.2
		Main roads	1.2	53.1	176.0
		Other roads	0.6	121.9	403.8
Bus	Metropolitan	Motorway	0.0	66.9	153.8
		Main roads	2.3	353.3	453.1
		Other roads	6.2	398.7	606.4
	Urban	Main roads	1.6	121.7	189.6
		Other roads	6.2	348.6	576.3
	Rural	Motorway	0.0	33.5	76.9
		Main roads	1.0	45.8	151.7
		Other roads	0.5	105.0	348.1

Source: Own calculations based on the FORGE estimates in Table 6. Values for the EU are derived from the UK values by means of value transfer, using the ratio of respective nominal GDPs per capita and the average exchange rate of year 2010 (0.86 GBP/EUR). Congestion bands (free flow, near capacity, over capacity) are defined in Table 7. Metropolitan: cities with the population > 250,000 people; urban: population > 10,000 people. All other areas are considered rural.

** Country-specific values are provided in Excel tables as Annexes to this report.*

The transfer of these values to other Member States and other points in time can be achieved by adjusting for variations in the value of time (similarly, income level). As the figures in Table 9 are in nominal Euro, for an adjustment to some country *c* in year *t* the figures should be multiplied by the ratio “GDP per capita of country *c* in year *t* over 24,400 €” (the latter being EU average nominal GDP per capita in 2010).

An alternative to this very rough procedure for calculating marginal congestion costs is the use of the full transport model like FORGE or other model, calibrated to country-specific conditions. Unfortunately, no easy adjustment of the illustrative values in Table 9 to specific local conditions is possible. The averages across road types and congestion bands can also only be calculated if the statistics on local distribution of traffic across these categories is available.

2.2.2 Other modes of transport

The study of the existing literature did not reveal many new sources (as compared to the 2008 Handbook) of marginal congestion or scarcity cost estimates for rail, air, or water transport that could be recommended as a best practice methodology. However, it is obvious that some national methodologies for pricing infrastructure access do take account of the variation of traffic flow e.g. according to time of the day and type of path (e.g. for rail), which suggests that the scarcity of slots at peak hours has an impact on the level of charges.

For **rail transport**, recent overviews of national practices in charging for infrastructure access have been carried out by the International Transport Forum (2008) and in the DICE Database (2012). Annex G includes an overview of access charges presented in these two sources.

The introduction of the ERMTS (standardised signalling developed to be used within Europe, but used elsewhere as well) has had a major impact on the reduction of delays in rail transport, both freight and passenger. The minimum headway between trains on some heavily used lines could be reduced to 2-3 minutes using the ERMTS level 2 (UNIFE, 2012). If true marginal congestion costs for rail transport were to be calculated, these facts must also be taken into account.

The marginal cost estimate for freight rail congestion as contained in the most recent version of the Marco Polo calculator (Brons and Christidis, 2013) is €0.2 per 1000 tkm (average for EU27, in 2011 prices). This number is derived from the studies reviewed in the 2008 Handbook. The average is calculated by assuming equal freight rail congestion costs in most EU countries at the level of €0.1 per 1000 tkm. For Italy, the estimated unit cost is €0.25, for Germany and France €0.4, and for Belgium and the Netherlands €0.5.

Jansson and Lang (2013) have developed a new methodology to evaluate the external delay costs in rail transport. In the application for passenger transport in Sweden, the authors estimate, 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 estimate 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. Overall, Jansson and Lang (2013) suggest that charging for delay costs should be introduced for the operators in the market that cause large negative external effects and whose customers have low valuation of wait and delay time (operators of commuter trains, in the example above). However, introducing such pricing schemes in practice may be difficult.

For **air transport**, EuroControl gathers data that allow delay costs to be calculated (see e.g. CODA, 2012). Earlier, EuroControl published a report (Cook et al., 2004) describing a methodology for evaluating true cost of flight delays. The methodology presents results detailing the cost to airlines of delays during various segments of a scheduled flight. The costs are divided into short delays (less than 15 min) and long delays (greater than 65 min). The report provides a cost factor (Euros per minute) for each flight segment. The types of delays considered include gate delay, access to runway delay (both taxi in and out delays), en-routes delays, and landing delays (circling or longer flight paths to overcome congestion while approaching the airport). The data used in the study consisted of data collected from European airlines, air traffic management as well as interviews and surveys conducted by the research team. The selected results of Cook et al. (2004) are reported in Annex A2.

For **inland waterway and maritime transport**, no illustrative quantification of marginal congestion costs could be identified in the recent literature. According to sectoral forecasts, however, the problem of port capacity will likely become very important in the nearest future. The findings of the 2008 Handbook on the topic were as follows:

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 shows 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 computation 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 in case 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, GRACE estimates scarcity costs between €0.38 to €0.50/TEU*km at Kaub and €0.65 to €1.25/TEU*km at Duisburg.

3. Accident costs

3.1 Methodological developments and new data sources

3.1.1 Methodology in road transport

External accident costs are those social costs of traffic accidents, which are not covered by risk oriented insurance premiums. Therefore, the level of external costs does not only depend on the level of accidents, but also on the insurance system (which determines the share of internal costs).

The most important accident cost categories are medical costs, production losses, material damages, administrative costs, and the so called risk value as a proxy to estimate pain, grief and suffering caused by traffic accidents in monetary values. Mainly the latter is not covered properly by the private insurance systems.

A comprehensive discussion of the methods and data used in the calculation of marginal external accident costs in road transport can be found in the deliverables of the GRACE project (Lindberg et al., 2006). They also cover the dedicated case studies of accident costs carried out during the UNITE (1998-2002) project. These key sources are the basis for the recommended methodology in the 2008 Handbook and in the update study by CE Delft et al. (2011). The core bottom-up methodology used there is stemming from Lindberg (2001) and it remains the most widely used approach until now.

The approach of Lindberg (2001) is quite intuitive. When an additional vehicle joins the traffic, the driver exposes himself/herself to the average accident risk, the historical value of which can be assessed by relating the number of accidents involving a given vehicle class to the traffic flow. Furthermore, an additional vehicle may change the accident risk of the other transport users. This effect is captured by the risk elasticity, for which various econometric estimates exist.

In order to obtain the marginal external cost value, the adjusted risk rate must be applied to the relevant accident cost value, whereby the internal cost elements must be excluded. The following costs are related to the accident risk:

- expected cost (of death and injury) due to an accident for the person exposed to risk,
- expected cost for the relatives and friends of the person exposed to risk,
- accident cost for the rest of the society (output loss, material costs, police and medical costs).

The first two cost elements are evaluated using the concept of willingness to pay for safety. The key indicator upon which the evaluation is carried out is the value of a statistical life (VSL). Usually, the assumption is made that the users internalise in their decisions the risk they expose themselves and their family to, valued as their willingness-to-pay for safety.

These considerations can be summarised in the following formula for the marginal external accident cost:

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

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

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

where r_i^v represents the accident risk for each vehicle type (v) and road type (i) calculated by dividing the number of personal damage (fatality or injury) cases X_i^v by the number of vehicle kilometers Q_i^v. The term $(a+b+c)$ reflects the average accident costs and E is the risk elasticity quantifying how much a 1% increase in traffic (measured in vkm) increases the accident risk in percent. Parameter θ^v quantifies the share of the accident costs that is internal for each vehicle category. The values of θ and E influence the fact whether the result of MC_i^v is positive or negative. If $\theta - E > 1$ then the marginal costs can turn negative meaning that with each vehicle entering the road the average accident cost decreases. Respectively, average accident cost always increases with each additional vehicle if $\theta - E < 1$. The costs $(a + b + c)$ cover all social costs of the accident, with a representing the cost of death or injury to the exposed individual and b representing the cost for relatives and friends of the exposed individual. Parameter c represents the costs for the rest of society. This includes various direct and indirect economic costs and is assumed to be in the order of 10% of value of safety per se (i.e., of the value of life for a fatality).

If more detailed information on the accidents is available, the formula above may be refined. For example, the much-cited Swiss case study of the UNITE project (Sommer et al. (2002)) makes additional use of the indicator of responsibility of the parties involved in the accident. In one of the calculations, the risk of the causer of the accident is assumed to be completely internal, but not the risk of the non-responsible victims. Such detailed data is, however, not available from the centralised EU road safety database, CARE, which is the most important source of comparable data for all Member States.

The costs for relatives and friends (parameter b above) are often not considered in the evaluation due to methodological difficulties. Some earlier studies (e.g. Lindberg, 2001) assume a value in the order of 10-50% of own risk. Due to lack of consensus on this point, it will be assumed that the estimates of the VSL correspond to the sum of parameters *a* and *b*.

The comprehensive literature review did not deliver much new evidence in the field of accident cost evaluation. Most recent studies are directly based on the values or methodology described in the 2008 Handbook. However, a few new sources should be mentioned.

MIRA (2010) assess external costs of transport for Flanders. For accident costs, the methodology of GRACE case studies (Lindberg et al., 2006) was used. In particular, this concerns the values of parameters θ and E. The number of accidents is taken from official statistics for Flanders, and the traffic flow is inferred from the MIMOSA model. The cost figures for the valuation of fatalities and injuries stem from HEATCO guidelines (2006). Overall, this is a standard approach, which is followed by many studies that do not contain own research on the various parameters underlying the marginal cost calculations. An application of this method for Cyprus is provided by Zachariadis (2008), while Díaz (2011) performs a similar exercise for Colombia.

A rather unconventional approach is taken by Sen et al. (2010) in estimating the marginal external accident costs in Delhi. They set $\theta = 1$ and $E = 0$. This assumes that the utility loss of the individual and the close persons is fully internalised in the transport users' decision process through insurance premiums and there is no risk externality. Normally, such calculations are made as kind of sensitivity analysis in other studies.

One unresolved issue in the literature is the quantification of the link between congestion and accident risk. An interesting methodological discussion is found in Fridstrøm (2011). One important observation there, which is based on Norwegian data analysis, is that risk elasticity E appears to be close to zero when congestion is assumed constant, but distinctly smaller than zero when congestion (traffic density) effects are taken into account. Furthermore, the analysis suggests that the marginal accident costs of motorcycles are large and similar to those of heavy goods vehicles (however, the external part of cost is substantially smaller for motorcycles), while the marginal external accident costs of passenger cars might be negative. An important element of calculations in Fridstrøm (2011) is the correction of the estimated elasticities by the inverse of the traffic share of a given vehicle category.

A discussion of the link between congestion and accident risk is continued by Wang et al. (2009). In a detailed study of a specific road section in the UK, they find that traffic congestion has little or no impact on the frequency of road accidents.

A recently finished road safety study DaCoTa (Thomas et al., 2013) assembled the most recent fact sheets based on the CARE database at the newly established Road Safety Knowledge System platform[4]. Some parameters necessary for deriving the marginal accident costs can be inferred from there (see below).

[4] http://safetyknowsys.swov.nl/index.html

3.1.2 Discussion of the input values

3.1.2.1 Average accident cost (risk value)

The basis for the measurement of the accident costs (the main element being the cost of fatality) are the estimates of the value of statistical life (VSL). These mostly come from valuation studies, where participants are asked to assess own willingness to pay for accident risk reduction. The question posed in such studies is different from the WTP studies related, for example, to air pollution costs. Therefore, the estimate of the VSL is not only different across countries, age groups, etc., but may also differ for different types of risk under assessment. The main reason is that the expected number of life years lost may differ substantially between different risk cases.

The UNITE case studies and the HEATCO study use a VSL estimate of €1.5 million (EU-15, in 1998 market prices, from Nellthorp et al. (2001)). This is only slightly higher than the value used in the air pollution studies, e.g. CAFE CBA (2005). OECD (2012), based on the results of a meta-analysis, suggests an EU27-wide general purpose central (median) value of €3.0 million in 2005 prices (PPP). However, this study also states that:

"standardised estimates across agencies in a country, or a group of countries, like the European Union, is a second-best option that results from deficiencies in the research base and other concerns".

This is because VSL values should be expected to vary across different countries to reflect differences in population and risk characteristics. Hence, whilst it is useful to include an EU-wide median VSL figure, country-specific values are preferable. With this factor in mind, it is important to maximise consistency in the methods and assumptions used for calculating country-level and EU-level VSLs. However, the OECD meta-analysis only reports an EU-wide VSL figure and does not include values for each Member State. Taking all of the above into account, for consistency between the EU-level and country-level figures, we have based the calculations below on the UNITE study, updated to represent the average income level in the EU in 2010 prices, which amounts to an EU-wide VSL of €1.7 million. The nominal increase from the original value is rather small due to inclusion of lower-income new Member States. The value of €1.7 million is actually very close to the value recommended by the HEIMTSA study for the valuation of air pollution effects, which is reported in Chapter 4 below. Country specific values are derived from HEATCO (2006). Both the UNITE and HEATCO studies draw upon consistent datasets.

All other components of the risk value are evaluated based on the key assumption on the level of the VSL. Following HEATCO (2006) recommendations, the value of a severe injury is assumed to be 13% of the fatality value, while a light injury is valued at 1% of the fatality value. Direct and indirect economic costs (parameter *c*) are valued at 10% of the VSL for fatalities, and at country-specific rates provided by HEATCO for injuries. All unit values calculated below are thus connected in a linear fashion to the central assumption of the VSL value of €1.7 million and could be adjusted by simple scaling if a different value of VSL is assumed.

3.1.2.2 Degree of risk internalisation

As mentioned above, several approaches can be used to determine the share of external costs in total accident costs. The key question here is – what is already covered by the insurance of the person exposed to risk. Sommer et al. (2002) distinguish three cases:

- The average accident risk is internalised by transport users;
- The average accident risk is not internalised;
- With view to the causation principle: the accident risk of the causer is internal, the risk of the non-responsible victim is external (Swiss approach).

The approach of Lindberg (2001) described above is similar to the Swiss approach in that it assumes that a part of accident risk is internalised. An estimate of the share of cost internalised by a road user can be calculated by dividing the number of fatalities inside a certain type of vehicle by the number of fatalities in accidents involving this vehicle type (thus, also counting victims inside other types of vehicles involved in the accidents). The intuition suggests that this share (parameter θ from the exposition above) is high for cars, but is probably low for trucks.

In the literature, the original estimates of θ (values different from 0 or 1) are rare. Link et al. (2007) derive the estimates for internal cost shares (fatalities only) from the CARE database (data from 2002-2003). The average values are: 0.73 for cars, 0.25 for HGVs and LDVs together, and 0.18 for buses.

In GRACE case studies, Lindberg et al. (2006) apply the values 0.76 for cars, 0.22 for LDVs and HGVs, and 0.16 for buses. These are the values that are applied in the calculations below.

For motorcycles, the internal cost share intuitively should be higher than for cars and generally close to 1. Fridstrøm (2011) applies an estimate equal to 0.8, which is a reasonably high value that is also used in the calculations.

Recent results of van Ommeren et al (2013) suggest a need for controlling for vehicle weight when defining such parameters for accidents between vehicles of the same type. For practical purposes of external cost pricing this is however not very relevant.

As already mentioned earlier, parts of the accident costs are paid by third-party insurance, and other parts are 'paid' by the victim having himself/herself caused the accident (either through own insurance or through suffering uncompensated damage, etc.). Thus, it is very important to consider the total volume of insurance fees related to the transport sector and the damage paid for outside the insurance system (also sometimes called 'self-insurance'). Within our cost estimation procedure, the focus is directly on the external part. For translating the external costs into the specific internalisation measures, the national liability systems have to be considered.

3.1.2.3 Risk elasticity

A number of studies suggest different values for the risk elasticity (parameter E from above). The roughest estimate (-0.25 irrespective of the vehicle or road type) is used by MIRA (2010) and Lindberg (2001).

More sophisticated estimates for single countries are available. Sommer et al. (2002) carried out an estimation by road type and found risk elasticities of -0.5, -0.25 and -0.62 for motorway, urban and other roads in Switzerland respectively. In a different approach, Fridstrøm (2011) distinguishes between light and heavy vehicles and corrects the elasticities for the vehicle's traffic share. The author argues that heavy vehicles' low traffic share accounts for the lower elasticity estimates in the literature. The suggestion is thus to multiply the elasticity with the inverse of the vehicle's traffic share. Fridstrøm thus establishes risk elasticities of -0.655 for light vehicles (cars and LDVs) and 0.321 for heavy vehicles. Due to their small traffic share, motorcycles have a risk elasticity similar to that of heavy vehicles. However, the latter findings cannot yet be generalised to other countries, and it is recommended to use a conservative risk elasticity estimate of -0.25 irrespective of the vehicle or road type.

3.2 Updated unit accident costs

3.2.1 Road transport

Similar to other cost categories, it is possible to calculate average and marginal accident costs. Marginal cost figures must take account of the response in the risk rates of other traffic participants, determined by the risk elasticity at the actual level of traffic volume. Average costs are generally easier to calculate based on the information collected, e.g. in the CARE database.

The EU Directive 2008/96/EC on road safety requires Member States to carry out the calculation of average social accident costs ($(a + b + c)$ from the methodological discussion above). The most recent source of such values is the Road Safety Knowledge System[5]. However, the estimates assembled there are not provided for all Member States and the relative magnitude of cost figures for different countries is not always reasonable. These numbers are provided for completeness in Appendix E, but the recommendation is to base calculations on the social cost figures stemming from the HEATCO project, which is the same source as used in the 2008 Handbook. Table 10 updates values in Table 5.3 of the HEATCO D5 (2006) to base year 2010.

Regarding the marginal accident costs estimation, the most cited source for a detailed evaluation of marginal costs by road and vehicle type remains the Swiss case study of the UNITE project (Sommer et al., 2002). The data upon which these values are based are already quite outdated. On the other

[5] http://safetyknowsys.swov.nl/Countries/Country_overviews.html

hand, no other European source provides details about the responsibility of the parties in road accidents, which is a very strong feature of the Swiss approach.

Conducting new research comparable to Sommer et al. (2002) is beyond the scope of this update. However, in order to illustrate the impact of using more recent accident numbers, Table 11 reports the central values for Germany and Belgium from the 2008 Handbook, appropriately updated to 2010 prices. In addition, it includes the values for Flanders produced by MIRA (2010) as well as our own calculations for Germany (with the data for 2010) using the same parameters as in the MIRA study: internal cost shares (θ) 0.76 for cars, 0.22 for LDVs and HGVs, and 0.16 for buses; and uniform risk elasticity (E) of -0.25.

Table 10: Average social accident costs, at market prices (PPP) in €2010.

Country	Fatality	Severe injury	Slight injury
Austria	2,395,000	327,000	25,800
Belgium	2,178,000	330,400	21,300
Bulgaria	984,000	127,900	9,800
Croatia	1,333,000	173,300	13,300
Cyprus	1,234,000	163,100	11,900
Czech Republic	1,446,000	194,300	14,100
Denmark	2,364,000	292,600	22,900
Estonia	1,163,000	155,800	11,200
Finland	2,213,000	294,300	22,000
France	2,070,000	289,200	21,600
Germany	2,220,000	307,100	24,800
Greece	1,518,000	198,400	15,100
Hungary	1,225,000	164,400	11,900
Ireland	2,412,000	305,600	23,300
Italy	1,916,000	246,200	18,800
Latvia	1,034,000	140,000	10,000
Lithuania	1,061,000	144,900	10,500
Luxembourg	3,323,000	517,700	31,200
Malta	2,122,000	269,500	20,100
Netherlands	2,388,000	316,400	25,500
Poland	1,168,000	156,700	11,300
Portugal	1,505,000	201,100	13,800
Romania	1,048,000	136,200	10,400
Slovakia	1,593,000	219,700	15,700
Slovenia	1,989,000	258,300	18,900
Spain	1,913,000	237,800	17,900
Sweden	2,240,000	328,700	23,500
Great Britain	2,170,000	280,300	22,200
EU average	**1,870,000**	**243,100**	**18,700**

Source: update of the values in Table 5.3 of the HEATCO Deliverable D5 (2006) to base year 2010. Each figure includes the value of safety per se (VSL for fatality, 13% of VSL for severe, 1% for light injury) and the value of direct and indirect economic costs (10% of VSL for fatality, severe and slight injury based on HEATCO (2005)). EU average based on the VSL of €1.7 million.

As mentioned above, the central values of Sommer et al. (2002) are based on the assumption that the costs of non-responsible victims are not internalised. In the methodology used by MIRA (2010) and in our own calculations, the implicit assumption is that a driver of any vehicle involved in an accident is fully responsible, no matter what kind of accident this is. For urban roads, the applied value of risk elasticity (-0.25) coincides for all reported estimates. For other roads, the use of this uniform value of risk elasticity in the new calculations makes external cost estimates larger than in Sommer et al. (2002), other things being equal.

Table 11: Marginal accident costs for selected cases, €ct/vkm (prices of 2010)

Vehicle and road type		2008 Handbook, Table 10, DE	Own calculations, DE	2008 Handbook, Table 10, BE	MIRA (2010), Table 136, Flanders
Passenger car	Urban roads	5.29	0.67	7.98	1.12
	Motorways	0.37	0.30	0.57	0.31
	Other non-urban roads	2.02	0.43	3.04	1.00
Truck	Urban roads	13.47	1.48	20.33	3.85
	Motorways	3.72	2.48	0.57	1.44
	Other non-urban roads	3.40	1.51	5.13	4.53
Motorcycle	Urban roads	38.90	13.05	58.72	16.95
	Motorways	0.26	0.99	0.38	5.17
	Other non-urban roads	6.92	5.70	10.45	16.03

Note: Road categories are the same as used in Sommer et al. (2002). Urban roads - roads inside urban settlement areas; motorways - non-urban motorways with separated lanes and central barrier; other non-urban roads - other roads outside urban settlement areas.

The inspection of the values above suggests that there are substantial differences primarily in the marginal cost estimates for urban roads. For other road types, the results are more similar and the slight divergence can be explained by the use of more recent accident and traffic data for Germany and Belgium.

For urban roads, both our updated results for Germany and the results of MIRA (2010) are significantly (5-9 times) smaller than the numbers in the 2008 Handbook that are based on the Swiss case study of Sommer et al. (2002). In order to understand this phenomenon, the case study calculations were repeated using the original Swiss data. The conclusion is that the difference is partly explained by the specific assumptions about the internal part of the risk, which are more detailed (but also more case-specific) in the Swiss case study. Furthermore, the reduction of marginal cost estimates can be explained by generally decreasing number of accidents in the last decade (there were 45% fewer accidents in the EU in 2010 than in 2000) and increasing traffic volumes that together reduce the statistical risk of accident.

Further investigating the results in Table 11, one can also notice a special pattern in the new results for HGVs on different types of road in Germany. According to German statistics[6], the share of fatal HGV accidents on motorways amounts to 50% of all fatal HGV accidents, which is very high, compared to other countries. Combined with the data on traffic flow, this produces a marginal accident cost figure for motorways that is higher than for other road types. In the original Swiss data, the share of motorway HGV accidents was in contrast only 20%.

The conclusion from the above exercise on the marginal accident costs is that country-specific values should be calculated, if allowed by data. The transfer of quite old numbers for other countries may lead to substantially biased results. The data in the CARE database contains all the relevant data, but not all of that is currently publicly available. For instance, the detailed information on injuries is lacking in the public domain. However, it is important to note that additional datasets that are not publicly available can be requested from the European Commission for research and analysis purposes.

For the following calculations, the information on the number of fatalities and the number of injuries from the CARE database (years 2005-2010, provided by DG MOVE) is used. For the marginal cost calculation, the same parameters as in the exercise above are used again.

[6] https://www.destatis.de/DE/ZahlenFakten/Wirtschaftsbereiche/TransportVerkehr/Verkehrsunfaelle/Verkehrsunfaelle.html

Table 12: Marginal accident cost estimates, €ct/vkm (prices of 2010)

	Car			HGV			Motorcycle		
State/Type	Motor-way	Other non-urban road	Urban road	Motor-way	Other non-urban road	Urban road	Motor-way	Other non-urban road	Urban road
Austria	0.5	0.4	0.9	5.8	1.8	3.8	0.4	5.6	12.1
Belgium	0.3	0.3	0.4	3.0	1.5	0.9	1.6	3.0	6.0
Bulgaria	0.1	0.1	0.3	0.5	0.5	1.1	0.0	0.0	0.1
Croatia	0.3	0.2	2.9	0.9	0.6	16.4	0.0	0.2	1.6
Cyprus	0.8	0.1	2.1	2.0	0.3	46.2	0.3	0.1	5.6
Czech Republic	0.1	0.2	0.2	1.1	0.6	1.0	0.0	0.2	0.2
Denmark	0.1	0.1	0.1	1.1	1.0	0.7	0.3	1.2	3.8
Estonia		0.4	0.2		0.5	0.8		0.2	0.2
Finland	0.1	0.1	0.1	0.2	0.5	0.3	0.3	1.1	2.1
France	0.1	0.2	0.2	0.4	0.5	0.7	0.9	2.3	7.8
Germany	0.2	0.4	0.6	2.4	1.3	1.5	0.6	3.3	8.5
Greece	0.2	0.2	0.2	0.9	1.3	1.3	0.1	0.1	0.4
Hungary	0.1	0.3	1.3	0.8	1.2	6.8	0.0	0.1	2.4
Ireland	0.1	0.2	0.1	1.7	1.4	0.6	0.2	0.4	0.3
Italy	0.1	0.2	0.6	2.1	1.0	4.0	0.1	0.2	1.5
Latvia		0.3	0.2		0.4	0.5		0.1	0.3
Lithuania		0.2	0.3		0.3	0.9		0.2	0.2
Luxembourg	0.9		0.1	1.8		0.1	23.8		3.5
Malta			3.6			17.3			0.7
Netherlands	0.0	0.1	0.1	0.3	2.3	1.2	0.2	4.5	11.6
Poland	0.1	0.2	0.5	0.6	0.6	1.9	0.0	0.1	0.4
Portugal	0.1	0.1	0.3	2.1	2.7	9.3	0.1	0.2	0.9
Romania	0.0	0.2	2.1	0.1	0.6	12.0	0.0	0.0	1.5
Slovakia	0.1	0.3	0.5	0.8	0.7	12.2	0.0	0.2	0.5
Slovenia	0.1	0.2	0.2	0.5	0.7	1.7	0.0	0.3	0.1
Spain	0.2	0.1	0.1	1.8	0.9	0.3	1.0	0.8	1.6
Sweden	0.3	0.3	0.3	1.2	1.0	0.9	1.0	3.4	8.1
Great Britain	0.1	0.1	0.2	0.9	0.5	0.3	0.4	1.3	2.1
EU average	**0.1**	**0.2**	**0.3**	**1.2**	**0.8**	**1.1**	**0.2**	**0.5**	**1.9**

Source: own calculations based on the accident statistics from the CARE database (average for 2005-2010)

Note: Road categories correspond to those in the CARE database: Motorway: Public road with dual carriageways and at least two lanes each way with central barrier or median present throughout the road. The minimum speed is not lower than 50 km/h and the maximum speed is not higher than 130 km/h (Except Germany where there is no speed limit is defined). Other non-urban road: road outside urban boundary signs. Urban road: road inside urban boundary signs.

Source of definitions: http://ec.europa.eu/transport/road_safety/pdf/statistics/cadas_glossary.pdf

Several caveats have to be mentioned with respect to the values presented in Table 12. First, if values are calculated based on accident statistics in a single year, this means rather high uncertainty for disaggregated results at country level, as the number of accidents in a single year may be low or zero, while at the same time one accident involving a bus may result in a large number of fatalities. Therefore, it is generally better to smooth the accident numbers by taking an average across time (as is done for the calculations in Table 12) or across countries. For general purposes, it is recommended to use the average values for the EU as an approximation of the typical marginal accident costs, because the limited number of observations on country-level (especially for smaller countries) may lead to extreme values, some of which can be observed in Table 12.

Furthermore, the level of unit accident costs is very sensitive to the values of critical input values (accident risk, risk elasticity, degree of internalisation). The estimates available from different national case studies are usually provided with wide intervals, ranging from negative values (if the accident risk is assumed completely internal) to large positive values (e.g. if the risk is assumed completely external).

It can be noted that the high uncertainty of the accident cost is a persistent feature. The values from the Swiss case study reported in the 2008 Handbook are presented with wide ranges that would easily incorporate the values in Table 12, including the outliers (in particular, for smaller countries).

The relative magnitude of the reported values for different vehicles can be explained by the CARE accident statistics. For example, the big (seven times) difference between the average EU values for cars and motorcycles on urban roads stems from the large difference in risk rates (number of accidents per vkm), which for motorcycles is an order of magnitude higher than for cars.

Furthermore, the numbers across countries may also differ for specific reasons. As an example, one can see that the average values for the EU are substantially lower than for Germany. A key reason for this is a much higher number of injuries per fatality in the German CARE data. In particular, the number of fatalities, serious injuries, and light injuries are in German data related roughly as 1:20:170 for the above selected vehicle types. In the data for the whole EU, these proportions are much lower, namely 1:8:42. Thus, the average number of injuries per accident is much lower when averaged across the EU, other things being equal. In the German case, the total costs of injuries is in fact five times the costs of fatalities, while for the EU this ratio only equals 1.5. One reason may be the varying degrees of underreporting of injury numbers. In all calculations, a correction for underreporting as suggested in the Handbook-2008 was applied (see Annex B). Possibly, these factors have to be increased for some Member States with poor data quality.

3.2.2 Other modes

In the European rail, air, and water transport sectors, accidents are in general much rarer than in road transport. Therefore, the evaluation of accident costs must be based on the average number of accidents across several years. The latest evaluation of this type was carried out by CE Delft et al. (2011, Table 20). They report an average accident cost value of €0.5 per 1000 pkm for passenger air transport and a value of €0.6 per 1000 pkm for passenger rail transport. For freight rail transport, the value is €0.2 per 1000 vkm. All of the accident costs may be considered external, that is why the marginal costs are equal to average costs.

4. Air pollution costs

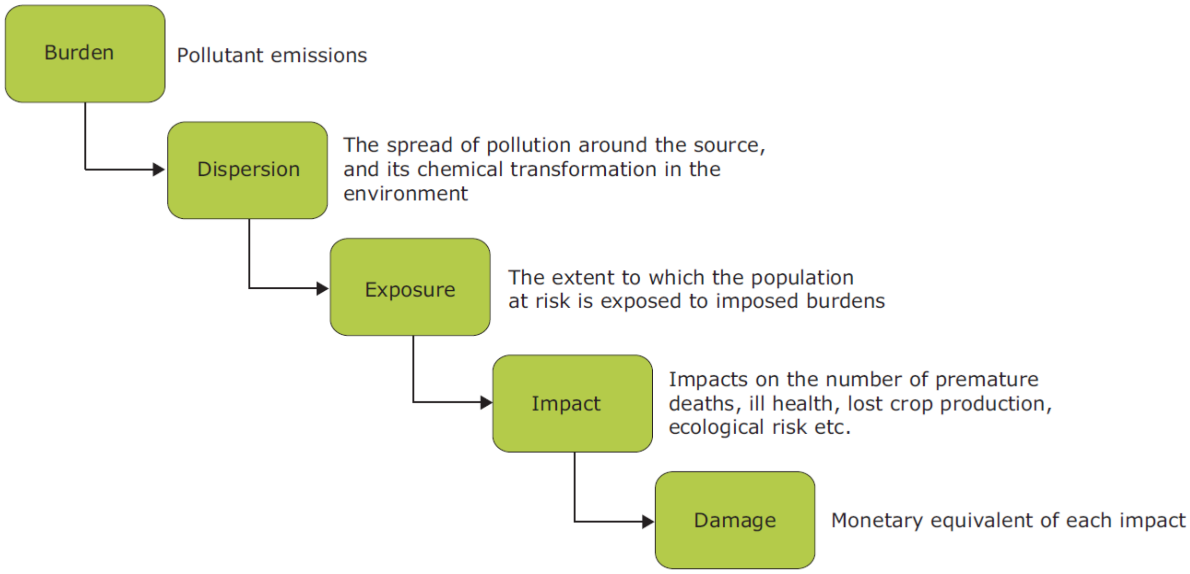
4.1 Methodological developments and new data sources

4.1.1 Recommended general methodology: Impact Pathway Approach

The state-of-the-art approach for evaluating air pollution effects is the *damage cost approach* or the *dose-response method*. This method focuses on the quantification of the explicit impact that the emissions have on human health, environment, economic activity, etc. Efforts undertaken in the last 20 years to develop standardised approaches involve a detailed analysis of the long chain of events preceding the final impact on the exposed population. The EU funded series of projects ExternE (finalised in Bickel and Friedrich (2005)) formalised this solution under the title **Impact Pathway Approach (IPA)**. This approach is used in the Handbook-2008.

The IPA follows a logical, stepwise progression from pollutant emissions to the determination of impacts and subsequently to the quantification of economic damage in monetary terms. The key steps of the IPA are illustrated in the following figure:

Figure 2: The Impact Pathway Approach (IPA)



Source: EEA (2011)

The first step quantifies the *burden* of pollutant emissions e.g. by using vehicle emission factors. The *dispersion* of the pollutants around the source is modelled using atmospheric dispersion models, which are very complex and are not typically publicly available. The impacts of transport air pollutant emissions are highly location-specific and depend on many factors such as the local traffic conditions. The *exposure* assessment therefore relates to the population and the ecosystem being exposed to the air pollutant emissions. Spatially detailed information on population density must be available to allow proper assessment. The *impacts* caused by the emissions are determined by applying so-called exposure response functions that relate changes in human health and other environmental damages to unit changes in ambient concentrations of pollutants - the most important being particulate matter (PM) and nitrogen oxides (NOx). These exposure response relations are based on epidemiological studies. Finally, the impacts of the emissions on humans and the ecosystem must be evaluated and transformed into *monetary values*. This step is often based on valuation studies assessing e.g. the willingness to pay for reduced health risks.

The IPA has been used in a large number of research projects and policy-related studies and is recognised as the most reliable tool for environmental impact assessment. Nevertheless, some uncertainties and limitations do exist. For instance, many pollutant pathways are fully characterised by the simple model as presented in Figure 2. A good example is the quantification of the effects of particulate matter emissions on human health, for which inhalation is the only relevant exposure route. However, for other pollutants (such as heavy metals) the pathways may be more complex.

As explained above, every step in the IPA requires a lot of detailed information, much of which cannot be updated within a single study that focuses on a specific issue. As a result, it is often the case that outdated information is transferred from study to study without proper correction or adjustment. The studies serving as core references for the 2008 Handbook recommendations suffer to some extent from this practice. However, this weakness cannot be easily corrected, as research teams typically apply best practices for certain steps in the procedure, but not for other steps. This also makes the comparison of the results of different integrated assessment studies very difficult.

The majority of the external costs from traffic-related air pollution arise through the effects on human health. For this most important part, the new developments identified during the comprehensive literature review can be structured into the following categories, which will be described in the next sections:

- **Burden estimation**:
  - New emission factors for vehicles
  - Vehicle fleet composition and traffic flow data
- **Dispersion modelling**:
  - New models of atmospheric chemistry
  - New meteorological data
- **Exposure modelling**:
  - New gridded population data
  - Specific urban studies
- **Health impacts**:
  - Updated dose-response functions for different pollutants
  - Assessment of relative toxicity of PM components
  - Evidence on health risks not covered by previous studies
- **Damage valuation**:
  - New stated preference studies, e.g. on mortality valuation.
  - General economic trends influencing damage valuation
- **Integrated assessment (national or European):**
  - New unit values for external costs

Country-specific values for air pollution costs (road and rail) are provided in Excel tables as Annexes to this report.

4.1.2 Overview of recent studies

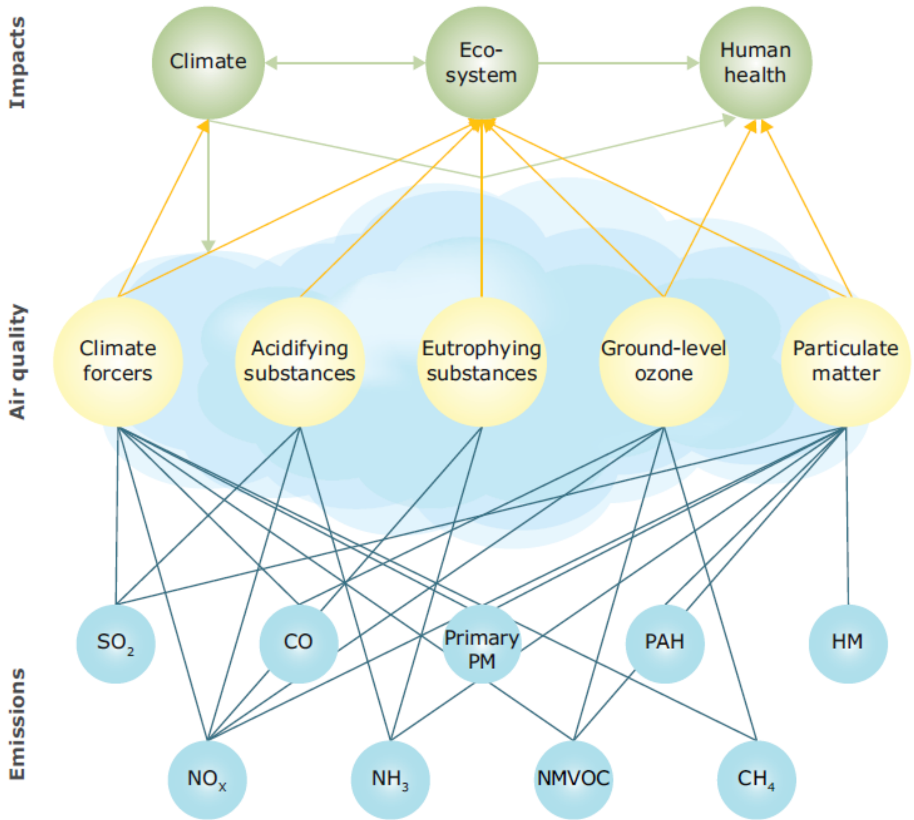
All major recent studies are listed in Table C-1 in Annex C. In the following sections, which follow the steps of the IPA, only studies with direct relevance for the purpose of updating the unit values for transport are mentioned.

4.1.2.1 Burden estimation

Emissions from transport contain a mixture of organic and non-organic, gaseous and particulate components, differing in size, shape, chemical and physical properties. The general distinction is made between directly emitted or **primary pollutants** and **secondary pollutants**. Primary pollutants are direct products of (incomplete) fuel combustion. These mainly include carbonaceous soot (also referred to as black carbon), nitrogen oxides (NO_x), sulphur dioxides (SO_2), carbon monoxide (CO), toxic volatile organic compounds (VOC), in particular benzene and 1,3 butadiene, some polycyclic aromatic hydrocarbons (PAH), and heavy metals. Secondary pollutants arise through atmospheric chemistry. The main secondary pollutants are ground-level ozone (O_3), nitrates and sulphates. Ozone is formed in the atmosphere through chemical reactions involving volatile organic compounds (VOC),

NO_x (which are referred to as ozone precursor gases) and sunlight. Nitrates and sulphates arise through oxidation of NO_x and SO_2, respectively. Some vehicle emission components thus have both direct effects on health through primary emissions and secondary effects through formation of secondary pollutants.

Figure 3: Major air pollutants in Europe, clustered according to impacts on human health, ecosystems and climate



Source: EEA (2012): Air Quality in Europe - 2012 Report

Identifying the causal effects between pollutant concentrations and human health effects becomes even more complex due to the difficulty of separate measurement of different components. In fact, most studies use mass measures for composites of particles, such as $PM_{2.5}$ or PM_{10}. The numbers indicate the size of the particles, i.e. less than 2.5 micrometres and less than 10 micrometres in diameter respectively. $PM_{2.5}$, or fine PM, contains primary combustion particles as well as secondary particles (sulphates, nitrates) that are small enough to penetrate into the alveolar gas exchange region of the lungs. The particles emitted from vehicle exhaust mostly, if not exclusively, belong to the fine PM category. Further traffic-related emissions (roughly 10%) stemming from brake and tyre wear as well as raised road dust are coarser, and belong to the category PM_{10}.

Official **EMEP/EEA Guidebooks**[7] provide detailed emission factors for all means of transport as well as for electricity generation (important to calculate emissions from electricity-powered trains). The newest emission factors for different road vehicle types used in these guidebooks stem from the COPERT[8] software tool and database. National sources, such as German (HBEFA, 2010) or British (TRL, 2009) methodology are (to the level of detail relevant for internalisation policies) consistent with COPERT. A widely used source of more aggregate emission factors, differentiated by country, type of region, type of vehicle, and vehicle technology is the **TREMOVE** database. It provides data for road, rail, air, and inland waterway transport in Europe. The latest publicly available version is TREMOVE v.3.3.2[9]. In TREMOVE, the relevant emission factors from COPERT v4 are used.

[7] http://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook
[8] http://www.emisia.com/copert/General.html
[9] http://www.tmleuven.be/methode/tremove/home.htm

For water-borne transport, one recent source of ship-specific emission factors (which are most relevant for port operators) is the Environmental Ship Index (ESI)[10]. The Environmental Ship Index (ESI) identifies seagoing ships that perform better in reducing air emissions than required by the current emission standards of the International Maritime Organisation, the Environmental Ship Index. The ESI evaluates the amount of nitrogen oxide (NO_x), sulphur oxide (SO_x) that is released by a ship and includes a reporting scheme on the greenhouse gas emission of the ship.

4.1.2.2 Dispersion modelling

The 2008 Handbook uses results on air pollution from two main studies: HEATCO (2006) and CAFE CBA (2005b). In HEATCO, the EcoSense software including the local scale ISC-USEPA model and the regional-scale WTM model has been applied to calculate the effects of pollutants (HEATCO, 2006, Annex D). In CAFE CBA, the RAINS/GAINS system has been applied. There has been recently some progress in the development of these and other models.

The EcoSense model has been updated in the NEEDS project (Preiss and Klotz, 2007). In the EcoSenseWeb model, the regional-scale model has been replaced by the EMEP/MSC-West Eulerian dispersion model, which is based on more recent meteorological data for the time period 1996-2000.

A recent study (Brandt et al. 2010) commissioned by the EEA relies on a different modelling package, namely the Danish EVA model system (Frohn, 2001; Brandt et al., 2013a, 2013b). The authors stress the advantage of using a model with non-linear atmospheric chemistry, compared with a simplified approach of the RAINS/GAINS or EcoSense systems. The non-linear chemistry comes in through the use of the regional Eulerian model DEHM. The local model OML is however quite standard and is as outdated as the ISC-USEPA model used in the EcoSenseWeb system. The study by Brandt et al. (2010) produced country-specific estimates of marginal air pollution costs for a large number of vehicle types (HGVs and buses), differentiated by road type.

Some other recent modelling can be found in the study of VITO (2010) for the Flanders. In this study, a BelEUROS model for Belgium is applied and compared with the EcoSenseWeb model. The authors claim to have more plausible results, in particular for local effects, because much additional local detail is included in BelEUROS. Due to the local character of the study, results for other countries are not available.

Overall, it is difficult to recommend any particular atmospheric model for all situations. However, a key selection criterion could be the quality of meteorological data. In this respect, the approach of the EVA model system appears to be most robust. Inside EVA, the MM5v3 meteorological model provides meteorological fields for the DEHM model on an hourly basis. This is contrasted with the alternative approach used by EcoSenseWeb and GAINS which apply an annual average of the meteorology. As a result, local and regional variability in the transports of pollutants due to instability in weather patterns is not accounted for in the latter models.

4.1.2.3 Exposure modelling

With respect to exposure modelling, there is an important difference between local pollutants, such as most particulate matter, and long-range pollutants, such as ozone. For local pollutants, population exposure in the immediate vicinity of the source of emissions largely determines the health impact. Thus, the impact assessment must at least take account of the differing population densities between the rural and urban areas, and, if possible, inside the large urban areas. For local analysis, the differentiation could be even more detailed. In the 2008 Handbook, the damage cost results of the HEATCO study (HEATCO, 2006) are used, where the air pollution effects of PM are provided separately for urban and non-urban areas. However, the procedure leading to these estimates is not very transparent and the link to respective population densities is not clear.

The country-specific damage cost values applied in Brandt et al. (2010) are only provided on the basis of average population densities. Similarly, only average damage values are available from NEEDS project (Preiss et al., 2008).

One recent source of area-specific damage cost values is the German methodology guidebook (UBA, 2012, p.12). It provides damage cost values of the main pollutants for Germany and for the EU

[10] http://esi.wpci.nl/Public/Home

average, differentiated between urban and non-urban areas. However, specific values for all Member States are not available.

In order to produce differentiated impact values for urban and rural areas without having them readily available as model output (i.e. when only the average is available), it seems reasonable to base the calculations on the population density data, as a first approximation. Eurostat provides population density values for predominantly urban, predominantly rural, and intermediate NUTS3 regions under the topic "Urban Development". The procedure used in this report to calculate area-specific damage costs based on the average values is described in Annex C3.

4.1.2.4 Health impacts

It is first useful to summarise the coverage of the main studies used by the 2008 Handbook, the CAFE CBA (2005b) and HEATCO (2006).

The CAFE and HEATCO studies both assess the health damages linked to PM and ozone exposure. The health effects considered include: new cases of chronic bronchitis, respiratory and cardiac hospital admissions, restricted activity days, and days of lower respiratory symptoms. For the most part, the scope of health effects matches between the two studies. However, CAFE separates the health impacts into a 'core' set of functions that are more robust and a 'sensitivity' set of functions that are less robust. HEATCO does not make this separation.

Both studies distinguish between chronic and acute health effects, with the terms **acute** and **chronic** referring to short- and long-term exposure to air pollution respectively. Hence, acute mortality relates to deaths brought forward as a result of pollution exposure over a period of days, while chronic mortality relates to deaths brought forward as a result of exposure over several months or even years. While in the case of PM exposure both studies evaluate chronic mortality effects, for ozone only acute mortality effects are included in the analysis.

When assessing the health impacts, both studies determine different risk groups affected by the health impacts. The main risk groups are classified into children below 14 years, adults of age between 15 and 65 and adults older than 65 years, with only small (i.e. one or two years) differences between the studies. In most cases, the risk groups related to the different health effects coincide, e.g. in both studies chronic bronchitis is only evaluated for the population aged over 27 years. However, while in HEATCO mortality effects due to PM and ozone exposure are quantified for the population as a whole, CAFE also assesses infant mortality caused by PM exposure. Concerning the health endpoint 'respiratory medication use', the risk groups in HEATCO are children and adults already suffering asthma, while in CAFE all adults and children are regarded as risk groups.

Another difference between the studies regarding the health effects is the valuation of mortality effects. While in HEATCO acute and chronic mortality are exclusively valued based on years of life lost (YOLL), in CAFE mortality effects are also quantified based on the value of a statistical life (VSL).

Table 13 documents the effects that were included in the HEATCO and CAFE studies, as well as additional effects for which some preliminary evidence exists. The column "Source" refers to the literature sources provided in Annex C (Box C-1). If no source is indicated, it means that the health effect was already included in the HEATCO and CAFE studies. The recommendation is to include the well-established effects into the core impact assessment, and to consider some other effects in the sensitivity analysis. For a large part of the harmful health effects (e.g. direct effects of NO_x, SO_2, VOC) only sparse supporting evidence has been collected so far, and it is therefore recommended that these effects should not be included in impact assessments at this point. The new references included in Table 13 are based on the review of work done in two connected EU projects, HEIMTSA and INTARESE.[11] These projects delivered highly relevant results on several topics, including a review of health impacts (dose-response functions) and updates on valuation of health endpoints (see next Section).

Table C-2 in Annex C reports the values of the response functions for PM used in some national studies as well as the original ExternE values used in CAFE CBA and the revision of these values reported by the HEIMTSA project. The results of the literature survey show that most EU and national studies use the ExternE response functions, with minor modifications. The joint work in HEIMTSA and INTARESE (Hunt et al., 2011) led to a revision of response functions for chronic bronchitis (a

[11] Results of both projects are gathered at the IEHIAS platform http://www.integrated-assessment.eu .

substantial increase of the risk estimate) and respiratory hospital admissions (slight reduction of the risk estimate). It is recommended that these latest estimates are applied in the new modelling exercises.

One of the most active on-going discussions in the specialised literature concerns the relative toxicity of different PM components. The approach taken in the ExternE project and adopted in the 2008 Handbook was to assume increased toxicity of the primary PM emissions from vehicle exhaust (1.5 times average $PM_{2.5}$ toxicity), and to assume reduced toxicity of secondary particles such as nitrates (0.5 times average PM_{10} toxicity). In CAFE CBA and later in NEEDS, these assumptions were discussed and discarded, because of the lack of evidence on relative toxicity.

Recent work of the NPACT project in the USA (inferred based on the HEI Annual Conference materials[12]), as well as the seminal publication of Bell (2012) conclude that is it impossible to make a precise quantification with existing tools and data. Therefore, it is recommended that in the impact assessment all traffic-exhaust PM components are weighted as equivalent to $PM_{2.5}$ in terms of their health impacts. Varying assumptions could of course be used in sensitivity analysis. In the following, we will use the approach with no differentiation of $PM_{2.5}$ toxicity with respect to source (i.e. assume same health effects from fine particles emitted by vehicles or by power plants).

[12] http://www.healtheffects.org/annual.htm

Table 13: Air pollutants and their effects on health

Pollutant			Impact (literature sources in Annex C)					Recommendation to include in the assessment
			Chronic or acute	*Impact on morbidity or mortality*	*Affected group*	*Specification of impact*	*Source*	
Primary Pollutants	PM_{10}, $PM_{2.5}$	Particulate Matter			Adults	All-causes		Core
			Chronic	Mortality	Infants (1-11 months)	All-causes		Core
						Respiratory		Core
						Cardio-pulmonary		Core
						Carcinogenic (cancer)	[1]	Sensitivity
					Adults	Cerebrovascular	[2]	
						Otitis media	[3]	
			Acute and Chronic	Morbidity	Children	Asthma	[4]	
	NO_2	Nitrogen Dioxides				Pulmonary effects in asthmatics	[5]	
						Reduced lung-growth	[5]	
			Acute			Leukaemia	[6]	
				Morbidity	Children	Asthma	[4]	
	SO_2	Sulphur Dioxides		Mortality	All	All-causes		
			Acute and Chronic	Morbidity	Adults	Cardio-pulmonary		
	CO	Carbon Monoxide			Adults (65+)	Congestive heart-failure		
				Mortality	Children	Sudden infant death syndrome	[7]	
					Adults	Cardio-vascular		
			Acute	Morbidity	Children	Reduced birth weight	[7]	
	PAHs	Hydrocarbons	Chronic	Morbidity	Adults	Carcinogenic (cancer)		Sensitivity
	As, Cd, Cr-VI, Ni	Toxic Metals	Chronic	Morbidity	Adults	Carcinogenic (cancer)		Sensitivity
	Hg, Pb	Mercury, Lead	Chronic	Morbidity	All	Neurotoxic diseases (IQ-Decrement)	[8]	
Secondary Pollutants	O_3 (NO_x + VOC)	Ozone		Mortality	All	All-causes		Core
						Respiratory		Core
						Pulmonary		
			Acute	Morbidity	All	Irritation of eyes, nose and throat	[9]	
	NO_3 (NO_x)	Nitrates		Mortality	All	All-causes	[10]	Core
						Respiratory	[11]	Core
			Chronic	Morbidity	All	Cardio-vascular	[11]	Core
	SO_4 (SO_2)	Sulphates		Mortality	All	All-causes	[12]	Core
						Respiratory	[11]	Core
			Chronic	Morbidity	All	Cardio-vascular	[11]	Core

4.1.2.5 Damage valuation

Table 14 summarises the monetary values for the main health end-points used in recent studies, expressed in 2010 Euros for convenience. The orders of magnitude are generally similar across studies, with some differences explained by local economic conditions. For the impact assessment, it is recommend that the values for **morbidity** effects collected for the common HEIMTSA/INTARESE case study (Hunt et al., 2011) are used. The central values should be used for core estimation, and low and high values are suitable for sensitivity analysis.

In the HEIMTSA project, new stated preference surveys have been conducted to determine the unit values for (the avoidance of) asthma attacks, chronic bronchitis and chronic obstructive pulmonary disease (Hunt et al., 2011). No European studies on these unit values existed before this study. The results for chronic bronchitis are such that the new central value is roughly three times lower than the value earlier recommended by ExternE (Bickel and Friedrich, 2005).

The most important question in the health effects valuation concerns the valuation of **mortality**, which represents the largest aggregate external cost component. The three most important valuation studies are: a three-country stated preference study by Alberini et al. (2006), a meta-analysis by Lindhjem et al. (2011); and a nine-country study by Desaigues et al. (2011). The latter study conducted during the NEEDS project provides the most recent estimate for the EU-25 mean value of a life year (VOLY) in the order of €40,000 (with a confidence interval €25,000 - €120,000, all in 2005 prices). These values are lower than those from Alberini et al. (2006) used in the ExternE, which can be explained by the incorporation of more (in particular, lower-income) countries in the survey. These estimates should be used for valuing **chronic mortality**. Corrected for nominal GDP/capita growth and taking into account the inclusion of newest EU members in the average, the appropriate value for 2010 is €43,000 (€27,000 - €130,000).

The HEIMTSA/INTARESE study as well as the work carried out in Denmark by NERI (Brandt et al. 2010) use an alternative valuation method for **acute mortality**, which is based on the value of a statistical life (VSL). This approach has been standard for mortality valuation for a long time and it certainly preserves its merit for the case of acute mortality, and in particular for the case of infant mortality. The latter view is also supported by OECD (2012), where the recommendation is to apply a scaling factor 1.5-2.0 to the adult VSL estimate in order to value infant mortality. It is recommended to base the central value for the adult VSL on the most recent HEIMTSA/INTARESE (Hunt et al., 2011) central value for the EU, which corresponds to €1,650,000 in 2010 prices.

An important aspect for the application of the VSL or VOLY in the impact assessment is whether these values must be differentiated across EU member states, or whether one value for the whole EU should be applied. Given the nature of these estimates, based on the willingness-to-pay surveys, it seems natural to let the values for different countries reflect the differences in the attitude to risk, income levels, etc. However, one can also argue that such differentiation must be avoided for ethical reasons (see e.g. van Wee and Rietveld (2013) for a discussion). In the recent report of EEA (2013), no differentiation of end-points valuation was made. The recommendation is to follow the approach in EEA (2013), where the EU as a whole is considered.

Table 14: Monetary values of health end-points (mortality and morbidity) used in different studies, in € (2010)

Effect\Study	CAFE CBA (2005b): EU	HEATCO (2006): EU	NSW (2005): Australia	Müller and Mendelsohn (2006): USA	AEA (2006): UK	Marbek (2007): Canada	IVL (2009): Sweden	NERI (2010): EU	HEIMTSA (2011): EU
Chronic mortality (VSL)									
mean	2,500,000		737,133	2,177,400		3,616,073	568,465		**1,650,000**
median	1,225,000							1,198,000	
Chronic mortality (VOLY)									
mean	150,155	56,437			44,204				60,000
median	65,067							63,550	
Infant mortality (VSL)									
mean	3,750,000								2,475,000
median	1,875,000							1,833,000	
Chronic bronchitis	237,746	214,264	157,118	351,903		237,500	196,395	232,000	60,000
Respiratory hospital admissions	2,503	2,661	2,849	9,127	2,896-13,871	1,786	2,518	2,450	2,990
Cardiac hospital admissions	2,503	2,661	5,139	19,273	3,049-14,023	3,929	4,269	2,450	2,990
Restricted activity days	104	106	139			43	132	101	194
Respiratory medication (bronchodilator) use by adults	1	1				25		1.2	80
LRS, including cough (adults)	48	43				13		46	57
Work loss days									441
Minor restricted activity days	48	43				20		46	57
Child acute bronchitis episodes			162			277			
Consultation with primary care physicians	66								

4.1.3 Update of input values

To sum up all quantified air pollution effects, the 2008 Handbook provides damage cost estimates per tonne of each pollutant. These are based on the HEATCO study for PM and on the CAFE CBA study for SO_2, NO_x, and NMVOC. The reason for using values stemming from different studies is the differentiation of PM damage by type of region in HEATCO.

In this report, the more recent damage costs from the NEEDS project (Preiss et al., 2008) are used instead. They are calculated by an updated version of the EcoSense model, which was used to calculate the damage costs in the HEATCO study. In addition to covering all major pollutants and all Member States, the values provided in NEEDS have several features that are especially relevant for the purpose of policy application. First, they cover all European sea territories (very relevant for correctly calculating the external costs of maritime transport). Second, they cover not only health effects (that surely correspond to over 90% of the total external effect), but also quantify the side effects of emitted NOx and SO_2 on materials (e.g. buildings), biodiversity, and crops. Overall, the levels of the damage costs of the main pollutant are highly correlated with alternative (and more recent) values provided by Brandt et al. (2010), but we choose to use the values from NEEDS due the advantages described above.

These values are provided for each EU Member State, and are based on average population exposure numbers per country. The numbers do not reflect differences in income levels across countries, as all health impacts are evaluated at average EU values (Table 14 above). In Annex C3, a procedure is suggested to differentiate the damage costs of PM by area type: rural, suburban, and urban. The reason is the importance of accounting for the actual exposure to health risks (highly correlated with population density) when evaluating the impacts of local pollutants. The resulting damage cost values are given in Table 15.

In order to calculate unit costs of air pollution for different types of vehicles, these damage costs must be combined with vehicle-specific emission factors of all relevant pollutants.

For road transport, the most widely used source of emission factors is the COPERT software tool and database. The current version, COPERT 4, is a software tool used world-wide to calculate air pollutant and greenhouse gas emissions from road transport. The development of COPERT is coordinated by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation.

The official EMEP/EEA Guidebook on the calculation of pollutant inventories for road transport (EMEP/EEA, 2012) builds upon the COPERT 4 methodology. Alternative sources of emission factors, such as the HBEFA Handbook, the Artemis model, or national sources, such as British NAEI/LAEI methodology, are either directly linked to COPERT or are using COPERT numbers for cross-checking of own estimates. It is thus recommended that COPERT emission factors are used for calculating unit costs for different vehicle types.

The factors for exhaust emissions are calculated using speed-emission factor equations, meaning that speed is an explicit input in the formula used to calculate the emission factors. Choosing the representative speed level appropriately thus allows differentiation of the emission factors also by type of road. For HGVs and buses, EEA (2013) differentiates between (sub)urban roads (35 km/h), interurban roads (55 km/h) and motorways (80 km/h).

It is important to note that the COPERT factors are based on experimental data and thus characterise the emissions performance of vehicles actually operating on roads. In the real world, the actual emissions factors differ from the emission factors obtained during type approval of vehicles. Moreover, vehicles designed to be most efficient in certain speed regimes may produce higher emissions in other regimes. Annex C includes some evidence demonstrating that dependence of emission factors on speed is nonlinear and differs across vehicle types.

For rail and air transport, the most up-to-date emission factors are contained in the dedicated EMEP/EEA Guidebooks. For water-borne transport, the recent study by CE Delft (2011) provides the most relevant information on emission factors, differentiated by characteristic vessel types.

Table 15: Damage costs of main pollutants from transport, in € per tonne (2010)

	$PM_{2.5}$			NO_x	NMVOC	SO_2
Country	**Rural**	**Suburban**	**Urban**			
Austria	37766	67839	215079	17285	2025	12659
Belgium	34788	60407	207647	10927	3228	13622
Bulgaria	34862	65635	212875	14454	756	12598
Croatia	31649	61539	208779	15149	1819	12317
Cyprus	25040	51200	198440	6465	1122	12594
Czech Republic	43028	68427	215667	15788	1648	14112
Germany	48583	73221	220461	17039	1858	14516
Denmark	13275	40760	188000	6703	1531	7286
Estonia	15359	49948	197188	5221	1115	8441
Spain	14429	48012	195252	4964	1135	7052
Finland	8292	43997	191237	3328	781	4507
France	33303	64555	211795	13052	1695	12312
Greece	19329	50605	197845	3851	854	8210
Hungary	47205	74641	221881	19580	1569	14348
Ireland	16512	47420	194660	5688	1398	6959
Italy	24562	50121	197361	10824	1242	9875
Lithuania	23068	55535	202775	10790	1511	10945
Luxembourg	45688	71308	218548	18612	3506	15103
Latvia	19528	53638	200878	8109	1499	10000
Malta	NA	NA	98132	1983	1007	6420
Netherlands	29456	48352	195592	11574	2755	16738
Poland	47491	74215	221455	13434	1678	14435
Portugal	18371	49095	196335	1957	1048	4950
Romania	56405	84380	231620	22893	1796	17524
Sweden	14578	50210	197450	5247	974	5389
Slovenia	39633	67670	214910	16067	1975	12422
Slovakia	54030	79270	226510	21491	1709	17134
United Kingdom	14026	47511	194751	6576	1780	9192
EU average	**28108**	**70258**	**270178**	**10640**	**1566**	**10241**

Source: NEEDS (Preiss et al. 2008), values for low height of release, updated to year 2010 using country-specific nominal GDP per capita (PPP) figures; own calculations for area-specific PM damage costs, explained in Annex C3. EU average values are also updated from NEEDS using EU average GDP figures.

Note: Urban - population density of 1500 inhabitants/km^2; suburban - population density of 300 inhabitants/km^2; rural - population density below 150 inhabitants/km^2 (see Annex C3 for further details).

For maritime transport, the air pollution effects have in the recent years become an important policy issue. In the NEEDS project, specific damage cost values for all major pollutants have been calculated for all European sea regions using the EcoSense model. Table 16 below reports these values, updated to the price level of 2010.

Table 16: Damage costs of main pollutants in sea areas, in € per tonne (2010).

Sea region	NMVOC	NOx	$PM_{2.5}$	SO_2
Baltic Sea	1100	4700	13800	5250
Black Sea	500	4200	22550	7950
Mediterranean Sea	750	1850	18500	6700
North Sea	2100	5950	25800	7600
Remaining North-East Atlantic	700	2250	5550	2900

Source: NEEDS (Preiss et al. 2008), updated to year 2010 using EU nominal GDP per capita (PPP) figures. All values are rounded.

4.2 Updated unit values for air pollution costs

4.2.1 Road transport

This section reports illustrative unit values that were calculated using the damage costs and emission factors recommended in the previous section. These unit values are representative for the EU and are calculated for the vehicle types actually present on European roads.

The source of exhaust emission factors of $PM_{2.5}$, NMVOC, and SO_2 for cars and light duty vehicles (LDVs) is the TREMOVE database (v.3.3.2)[13]. NO_x emission factors, which have been updated substantially by the recent research, are taken directly from the COPERT database. Emission factors for EURO 6 vehicles are calculated based on the EMEP/EEA emission inventory guidebook 2009 (updated in 2012). The reason for relying on the TREMOVE database for the largest part of calculations is the convenient definition of vehicle types and road types. The extracted emission factors have been cross-checked to guarantee consistency with the EMEP/EEA guidelines.

The source for the emission factors of heavy goods vehicles (HGVs) and buses is the Excel Annex accompanying the road transport exhaust emission guidebook (EMEP/EEA, 2012). It includes the speed-emission factor equations, which are the same as in the COPERT software tool. The same representative traffic situations for HGVs and buses as in the EEA (2013) study are chosen: (sub)urban roads (35 km/h), interurban or rural roads (55 km/h) and motorways (80 km/h). For lorries, 100% load is assumed, as well as 0% average road slope.

Non-exhaust $PM_{2.5}$ emission factors for road transport are taken from the EMEP/EEA guidelines (EMEP/EEA, 2009b, p.14). The corresponding damage cost factors are the same as for the exhaust emissions, because the applied PM measure is also the same.

The following tables report the marginal external cost values separately for passenger cars, light commercial vehicles, HGVs, and buses. The results are differentiated by area and road type, for which respective damage costs from Table 15 are applied. Urban areas are characterised by an average population density of 1500 inhabitants/km^2, while suburban areas - by an average population density of 300 inhabitants/km^2 (see Annex C). For rural areas, population density is below 150 inhabitants/km^2. Motorways and other interurban roads in rural areas differ in terms of speed, which is higher on the motorways (this is reflected in the corresponding emission factors).

Overall, the unit costs are higher for vehicles with larger engines, for vehicles with lower EURO standard, and for urban zones in comparison to rural zones. However, some exceptions from this general pattern exist, which are mentioned below.

Several aspects should be noted with respect to the unit costs of car emissions. First, there is a slight increase in the unit cost between the EURO 2 and EURO 3 diesel cars on interurban roads and motorways. The reason for this is a clear increase in NO_x emission factor for EURO 3 diesel cars, which is revealed by the COPERT data. The described phenomenon is also documented in Borken-Kleefeld and Ntziachristos (2012). This NO_x effect in the unit costs is visible for the non-urban areas only, because for urban areas it is compensated by the higher damage cost of PM.

Second, the unit costs on motorways are slightly higher than on other interurban roads, which is explained by the higher corresponding emissions factors of NO_x and PM in the data (due to nonlinear dependence of emission factors on speed, the emissions are at the minimum in the speed regime corresponding to interurban roads, and are higher for lower and higher speed regimes).

[13] http://www.tremove.org/index.htm

Table 17: Air pollution costs in €ct/vkm (2010) for passenger cars, EU average*

Vehicle	Engine	EURO-Class	Urban (€ct/vkm)	Suburban (€ct/vkm)	Rural (€ct/vkm)	Motorway (€ct/vkm)
Car diesel	<1.4l	Euro 2	3.6	1.5	0.8	0.8
		Euro 3	2.5	1.2	0.8	0.9
		Euro 4	1.7	0.9	0.6	0.6
		Euro 5	0.9	0.6	0.4	0.4
		Euro 6	0.7	0.3	0.2	0.2
	1.4-2.0l	Euro 0	9.9	3.1	0.9	0.9
		Euro 1	3.6	1.5	0.8	0.9
		Euro 2	3.2	1.4	0.7	0.8
		Euro 3	2.6	1.3	0.8	0.9
		Euro 4	1.8	0.9	0.6	0.6
		Euro 5	0.9	0.6	0.4	0.4
		Euro 6	0.7	0.3	0.2	0.2
	>2.0l	Euro 0	10.3	3.4	1.2	1.3
		Euro 1	3.7	1.5	0.8	0.9
		Euro 2	3.3	1.4	0.8	0.8
		Euro 3	2.6	1.3	0.8	0.9
		Euro 4	1.8	0.9	0.6	0.6
		Euro 5	0.9	0.6	0.4	0.4
		Euro 6	0.7	0.3	0.2	0.2
Car petrol	<1.4l	Euro 0	3.5	3.2	2.2	2.7
		Euro 1	1.0	0.7	0.3	0.4
		Euro 2	0.7	0.4	0.2	0.2
		Euro 3	0.4	0.2	0.1	0.1
		Euro 4	0.4	0.2	0.1	0.1
		Euro 5	0.4	0.2	0.1	0.1
		Euro 6	0.4	0.2	0.1	0.1
	1.4-2.0l	Euro 0	3.6	3.3	2.8	3.4
		Euro 1	1.1	0.8	0.3	0.4
		Euro 2	0.7	0.4	0.2	0.2
		Euro 3	0.4	0.2	0.1	0.1
		Euro 4	0.4	0.2	0.1	0.1
		Euro 5	0.4	0.1	0.1	0.1
		Euro 6	0.4	0.1	0.1	0.1
	>2.0l	Euro 0	3.8	3.5	2.8	3.5
		Euro 1	1.0	0.7	0.3	0.4
		Euro 2	0.6	0.4	0.2	0.2
		Euro 3	0.4	0.2	0.1	0.1
		Euro 4	0.4	0.2	0.1	0.1
		Euro 5	0.4	0.1	0.1	0.1
		Euro 6	0.4	0.1	0.1	0.1

Source: Own calculations based on emission factors from the TREMOVE v.3.3.2 model. Emission factors for Euro 6 vehicles are calculated based on the EMEP/EEA Guidebook (2012). Damage cost factors from Table 15.

Note: Urban areas - population density of 1500 inhabitants/km^2; suburban areas - population density of 300 inhabitants/km^2; rural areas and motorways - population density below 150 inhabitants/km^2 (see Annex C3 for further details).

** Country-specific values are provided in Excel tables as Annexes to this report.*

Table 18: Air pollution costs in €ct/vkm (2010) for light commercial vehicles, EU average*

Vehicle	EURO-Class	Urban	Suburban	Rural	Motorway
		(€ct/vkm)	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*
LCV petrol	Euro 1	1.3	0.9	0.5	0.5
	Euro 2	0.8	0.5	0.2	0.2
	Euro 3	0.7	0.4	0.2	0.1
	Euro 4	0.6	0.3	0.1	0.1
	Euro 5	0.6	0.2	0.1	0.1
	Euro 6	0.6	0.2	0.1	0.1
LCV diesel	Euro 1	5.3	2.4	1.4	1.3
	Euro 2	5.9	2.5	1.4	1.3
	Euro 3	4.6	2.0	1.1	1.1
	Euro 4	3.2	1.5	0.9	0.8
	Euro 5	1.4	0.8	0.6	0.6
	Euro 6	1.1	0.5	0.3	0.3

Source: own calculations based on emission factors from the TREMOVE v.3.3.2 model. Emission factors for Euro 6 vehicles are calculated based on the EMEP/EEA Guidebook (2012). Damage cost factors from Table 15.

Note: Light commercial vehicles are goods vehicles (e.g. vans) with a maximum gross vehicle weight of 3.5 tonnes. Urban areas - population density of 1500 inhabitants/km^2; suburban areas - population density of 300 inhabitants/km^2; rural areas and motorways - population density below 150 inhabitants/km^2 (see Annex C3 for further details).

** Country-specific values are provided in Excel tables as Annexes to this report*.

Table 19: Air pollution costs in €ct/vkm (2010) for buses and coaches, EU average*

Vehicle	Category	EURO-Class	Urban	Suburban	Rural	Motorway
			€c/vkm	€c/vkm	€c/vkm	€c/vkm
Urban Buses	Midi <=15 t	EURO 0	30.2	15.5	10.4	9.5
		EURO I	15.9	9.8	7.0	6.0
		EURO II	13.2	9.4	7.1	6.1
		EURO III	11.4	7.9	5.4	4.3
		EURO IV	6.7	5.1	3.7	3.0
		EURO V	5.8	4.2	2.4	1.9
		EURO VI	1.8	0.7	0.3	0.3
	Standard 15 - 18 t	EURO 0	35.6	21.7	15.3	12.9
		EURO I	21.1	13.1	9.2	7.8
		EURO II	17.4	12.5	9.3	7.9
		EURO III	14.7	10.4	7.2	5.8
		EURO IV	8.6	6.7	4.9	3.9
		EURO V	6.9	5.0	2.8	2.2
		EURO VI	1.9	0.8	0.4	0.3
	Articulated >18 t	EURO 0	46.4	28.5	19.8	16.3
		EURO I	27.3	17.2	12.0	9.8
		EURO II	22.1	16.0	11.8	9.8
		EURO III	18.5	13.3	9.3	7.5
		EURO IV	10.8	8.7	6.6	4.6
		EURO V	7.0	4.9	3.0	2.3
		EURO VI	2.0	0.8	0.5	0.4
Coaches	Standard <=18 t	EURO 0	28.8	17.4	11.9	10.4
		EURO I	22.7	13.4	8.9	7.7
		EURO II	18.1	13.1	9.4	8.1
		EURO III	17.0	11.5	7.6	6.4
		EURO IV	9.0	7.0	5.1	4.5
		EURO V	10.0	7.9	4.4	2.7
		EURO VI	2.5	1.3	0.6	0.4
	Articulated >18 t	EURO 0	34.9	21.5	14.7	12.5
		EURO I	26.9	16.3	10.9	9.2
		EURO II	21.4	15.7	11.2	9.5
		EURO III	19.2	13.2	8.8	7.2
		EURO IV	10.3	8.1	5.9	5.0
		EURO V	10.6	8.4	4.6	2.7
		EURO VI	2.4	1.3	0.6	0.4

Source: own calculations based on COPERT 4 emission factors. Damage cost factors from Table 15.

Note: Urban buses are Class M2 and M3 heavy duty passenger vehicles generally used for providing local public transport services. Coaches are M3 heavy duty passenger vehicles generally used for providing inter-city passenger transport services. Urban areas - population density of 1500 inhabitants/km^2; suburban areas - population density of 300 inhabitants/km^2; rural areas and motorways - population density below150 inhabitants/km^2 (see Annex C3 for further details).

** Country-specific values are provided in Excel tables as Annexes to this report.*

Table 20: Air pollution costs in €ct/vkm (2010) for heavy goods vehicles, EU average*

Vehicle	Category	EURO-Class	Urban	Suburban	Rural	Motorway
			€c/vkm	€c/vkm	€c/vkm	€c/vkm
Rigid HGV	<=7,5 t	EURO 0	15.4	7.7	5.6	5.9
		EURO I	8.5	4.8	3.8	4.1
		EURO II	6.9	4.6	3.8	4.1
		EURO III	6.1	3.7	2.9	3.1
		EURO IV	3.8	2.5	2.1	2.1
		EURO V	3.7	2.3	1.2	0.8
		EURO VI	1.7	0.6	0.3	0.2
	7,5 - 12 t	EURO 0	20.5	12.4	9.4	9.3
		EURO I	13.0	7.6	5.7	5.6
		EURO II	10.5	7.2	5.8	5.7
		EURO III	9.1	5.9	4.5	4.3
		EURO IV	5.4	3.9	3.2	3.0
		EURO V	5.2	3.6	1.8	1.2
		EURO VI	1.8	0.7	0.3	0.3
	12 - 14 t	EURO 0	22.5	13.8	10.3	9.8
		EURO I	14.4	8.5	6.2	5.9
		EURO II	11.6	8.1	6.3	6.0
		EURO III	10.1	6.8	5.1	4.6
		EURO IV	6.0	4.4	3.5	3.2
		EURO V	5.5	3.9	2.0	1.3
		EURO VI	1.8	0.7	0.3	0.3
	14 - 20 t	EURO 0	29.0	17.8	12.8	11.6
		EURO I	18.3	10.9	7.7	7.0
		EURO II	14.5	10.4	7.9	7.2
		EURO III	13.0	8.8	6.4	5.5
		EURO IV	7.3	5.5	4.3	3.8
		EURO V	7.4	5.6	3.0	1.7
		EURO VI	2.1	1.0	0.4	0.3
	20 - 26 t	EURO 0	31.8	20.0	14.2	12.2
		EURO I	23.8	14.3	10.0	8.6
		EURO II	18.9	13.6	10.1	8.8
		EURO III	16.3	11.2	8.1	7.1
		EURO IV	9.1	7.1	5.6	4.9
		EURO V	8.3	6.3	3.3	2.0
		EURO VI	2.1	1.0	0.5	0.3
	26 - 28 t	EURO 0	33.4	21.0	15.0	12.8
		EURO I	25.0	15.1	10.5	9.0
		EURO II	19.9	14.2	10.6	9.1
		EURO III	16.9	11.6	8.4	7.2
		EURO IV	9.4	7.3	5.7	5.0
		EURO V	8.4	6.3	3.3	2.1
		EURO VI	2.1	1.0	0.5	0.4
	28 - 32 t	EURO 0	38.2	24.2	17.4	14.9
		EURO I	28.5	17.4	12.3	10.5
		EURO II	22.8	16.4	12.2	10.6
		EURO III	19.1	13.3	9.7	8.3
		EURO IV	10.7	8.5	6.7	5.6
		EURO V	8.5	6.2	3.3	2.3
		EURO VI	2.1	0.9	0.5	0.4
	>32 t	EURO 0	39.2	25.1	17.7	14.8
		EURO I	29.8	18.1	12.5	10.5
		EURO II	23.7	17.0	12.5	10.6
		EURO III	19.9	13.9	10.1	8.4
		EURO IV	10.9	8.7	6.8	5.8
		EURO V	8.5	6.3	3.4	2.3
		EURO VI	2.1	0.9	0.5	0.4

Vehicle	Category	EURO-Class	Urban €c/vkm	Suburban €c/vkm	Rural €c/vkm	Motorway €c/vkm
Articulated HGV	14 - 20 t	EURO 0	28.5	17.6	12.5	11.0
		EURO I	17.9	10.7	7.5	6.6
		EURO II	14.4	10.3	7.7	6.8
		EURO III	12.6	8.6	6.1	5.3
		EURO IV	7.2	5.5	4.2	3.7
		EURO V	6.8	5.1	2.7	1.6
		EURO VI	2.0	0.9	0.4	0.3
	20 - 28 t	EURO 0	32.2	20.4	14.4	12.0
		EURO I	24.4	14.8	10.2	8.6
		EURO II	19.4	13.8	10.1	8.6
		EURO III	16.4	11.4	8.1	6.7
		EURO IV	9.2	7.2	5.5	4.6
		EURO V	7.8	5.8	3.0	2.0
		EURO VI	2.0	0.9	0.4	0.4
	28 - 34 t	EURO 0	34.7	22.2	15.5	12.8
		EURO I	26.2	16.0	10.9	9.0
		EURO II	20.8	14.9	10.7	9.0
		EURO III	17.4	12.2	8.6	7.0
		EURO IV	9.8	7.8	5.8	4.8
		EURO V	7.6	5.5	3.0	2.0
		EURO VI	2.0	0.9	0.5	0.4
	34 - 40 t	EURO 0	40.9	26.3	18.1	14.8
		EURO I	31.1	18.9	12.7	10.4
		EURO II	24.7	17.7	12.7	10.4
		EURO III	20.5	14.4	10.2	8.3
		EURO IV	11.2	9.0	6.9	5.6
		EURO V	8.5	6.2	3.4	2.3
		EURO VI	2.1	0.9	0.5	0.4
	40 - 50 t	EURO 0	46.5	30.2	21.0	17.1
		EURO I	35.4	21.7	14.7	11.7
		EURO II	28.0	20.1	14.5	11.8
		EURO III	23.0	16.4	11.6	9.3
		EURO IV	12.5	10.3	7.9	6.3
		EURO V	8.5	6.1	3.5	2.5
		EURO VI	2.1	0.9	0.5	0.5
	50 - 60 t	EURO 0	56.6	37.2	25.9	20.2
		EURO I	43.1	26.6	17.9	14.0
		EURO II	33.9	24.5	17.5	14.1
		EURO III	27.4	19.7	14.1	10.9
		EURO IV	15.1	12.6	9.5	7.5
		EURO V	9.4	6.7	4.1	3.0
		EURO VI	2.2	1.0	0.6	0.6

Source: own calculations based on COPERT 4 emission factors. Damage cost factors from Table 15.

Note: Urban areas - population density of 1500 inhabitants/km^2; suburban areas - population density of 300 inhabitants/km^2; rural areas and motorways - population density below 150 inhabitants/km^2 (see Annex C3 for further details).

** Country-specific values are provided in Excel tables as Annexes to this report.*

Two phenomena must be stressed with respect to the results for HGVs. First, NO_x emission factors are higher for EURO II HGVs and buses, than for EURO I. This is a result of engine tuning, needed to meet strict PM norms of EURO II[14]. This fact is reflected in the unit values for motorways, which are higher for EURO II, than for EURO I (for urban areas, the effect of higher local PM costs is stronger and no such result is observed).

Second, the general result for LDVs, HGVs, and buses is that the unit costs on motorways are lower than unit costs on other non-urban roads (rural, interurban) roads. The only exceptions are the values for the early EURO classes in the category “rigid HGVs under 7.5 tonnes”. As the COPERT factors are based on the experimental data, it can be concluded that the engines of these vehicles are tuned so that they are more efficient in terms of NO_x emissions on lower speeds, compared to heavier HGVs.

4.2.2 Other modes of transport

4.2.2.1 Rail transport

The air emissions from diesel-driven rail transport are in general evaluated in the same way as emissions from road transport. A special treatment must however be given for electrically powered trains, for which emissions must be inferred indirectly based on the fuel mix of the power plants in the given country. These indirect emissions are covered later on in Chapter 7 on the costs of up- and downstream processes.

The major pollutants from diesel fuel combustion and the corresponding damage costs (area-specific for PM) are the same as described in the sections on road transport above. The damage costs are provided in Table 15. The most recent and consistent overview of exhaust emission factors (per kg of fuel input) from diesel-driven trains is contained in the dedicated Railways Guidebook of EMEP/EEA (2009a). In order to calculate unit costs for the EU, these emission factors are combined with the data on traffic flow and fuel use stemming from the TREMOVE v.3.3.2 database. It allows differentiation between passenger and freight trains as well as differentiation between urban and non-urban passenger trains. In addition, TREMOVE differentiates between locomotive-driven passenger trains and railcars (i.e. multiple units - meaning modern trains without an explicit locomotive unit, but where each railcar has its own engine). Types of trains in TREMOVE are differentiated by load factors (freight) and occupancy rates (passenger).

In contrast to road transport, there is lack of a methodology for calculating non-exhaust emissions from rail transport (Abbasi et al., 2013). The recent EMEP/EEA Guidebook 2013 also lacks information on this topic. One source that provides non-exhaust PM emission factors from freight rail transport is CE Delft (2011, p.28). They provide an estimate of 15 grams of PM_{10} per train-km, which is 2-3 times more than the amount of exhaust PM emissions. This evidence suggests that wear and tear PM emissions are a more important source of external costs for rail transport, than the exhaust PM emissions. The unit costs summing up the exhaust and non-exhaust emissions are given in
Table 21. For lighter passenger trains the non-exhaust emissions are assumed to be 10 grams of PM_{10} per train-km for high-speed trains and 6 grams for other trains (these assumed rates are proportional to average TREMOVE energy use figures, as a proxy for weight). For electric trains, only costs of wear and tear PM emissions are reported in
Table 21.

[14] Explanation suggested in a private communication by Leonidas Ntziachristos (COPERT expert).

Table 21: Marginal air pollution costs (2010) for rail transport, EU average*

Type of train		Urban			Suburban			Rural		
		Unit cost		Load factor	Unit cost		Load factor	Unit cost		Load factor
		€ct/ pkm €ct/ tkm	*€ct/ train-km*	*pax or tonne*	*€ct/ pkm €ct/ tkm*	*€ct/ train-km*	*pax or tonne*	*€ct/ pkm €ct/ tkm*	*€ct/ train-km*	*pax or tonne*
Passenger diesel	Locomotive	2.8	348.7	125	1.4	174.2	125	0.9	149.7	159
	Railcar (multiple unit)	2.5	294.3	120	1.1	135.7	120	0.9	106.8	120
Freight diesel	Locomotive							0.6	312.5	500
Passenger electric	Locomotive	0.8	162.1	195	0.2	42.2	195	0.09	16.9	195
	Railcar (multiple unit)	1.4	162.1	120	0.4	42.2	120	0.14	16.9	120
	High-speed							0.18	28.1	154
Freight electric	Locomotive							0.08	42.2	500

Source: Own calculations based on exhaust emission factors of rail diesel fuel from EMEP/EEA (2009a). Fuel use data and load factors from TREMOVE v.3.3.2. Non-exhaust PM emission factor for freight trains from CE Delft (2011). Damage cost factors of main pollutants from Table 15.

Note: Urban - population density of 1500 inhabitants/km^2; suburban - population density of 300 inhabitants/km^2; rural - population density below 150 inhabitants/km^2 (see Annex C3 for further details). For suburban areas, the same unit emission factors as for urban areas are assumed. For electric trains, only non-exhaust emissions are reported. Values for railcars are for a complete train composed of multiple railcar units.

* Country-specific values are provided in Excel tables as Annexes to this report.

4.2.2.2 Air transport

For air transport, a comprehensive dataset on emissions from different types of aircraft is provided in the Annex to the dedicated EMEP/EEA Aviation Guidebook (2010a). In order to provide illustrative unit values, the approach of the IFEU et al. (2011) report is adopted by choosing one representative aircraft type for each of three trips lengths: short, medium and long haul. The assumptions on typical range, capacity, and capacity utilisation for these aircraft types are carried over from IFEU et al. (2011, Tables 12 and 42).

As in the 2008 Handbook, it is further assumed that the air quality relevant pollutant emissions of aviation are restricted to the emissions in the landing and take-off (LTO) phase. These emission factors are taken from EMEP/EEA (2010a). The damage factors applied for valuing PM emissions are the ones for rural areas (see Table 15).

Table 22: Marginal air pollution costs (2010) for passenger aviation, EU average

Distance group	Type of aircraft	Range	Typical seats number	Average capacity utilisation	Air pollution costs	
					€/LTO	€ct/pkm
Short haul	Fokker 100	< 1000 km	85	65%	75	0.27
Medium haul	Airbus A320	< 3700 km	150	70%	134	0.05
Long haul	Boeing 747-400	> 3700 km	416	80%	648	0.03

Source: own calculations based on emission factors from EMEP/EEA (2010a). LTO = landing and take-off.

4.2.2.3 Inland waterway freight transport (IWT)

For water-borne transport, there also exists an EMEP/EEA Guidebook on calculating the pollutant emissions (EMEP/EEA, 2011). It allows calculating the emission factors for specific vessel and engine types. One particularly important pollutant from shipping is sulphur. According to the latest regulations (Directive 2005/33/EC), the sulphur content of fuel cannot exceed 0.1% for inland waterway vessels and ships at berth in Community ports. The relevant emission factors thus have to relate to the use of low-sulphur oil.

Moreover, Brons and Christidis (2013) report emission correction factors for more advanced fuel technologies in IWT. Brons and Christidis (2013) also report the marginal cost estimates (in € per 1000 tkm) of the Marco Polo calculator. However, a dedicated study by CE Delft (2012) suggests that the TREMOVE load factors for IWT, upon which these calculations were based, are too low. This conclusion is confirmed by comparing the Marco Polo estimates with two recent studies: NEA et al. (2011) and CE Delft et al. (2010).

For the current report, we use the emission factors stemming from the STREAM database (CE Delft, 2008) as reported by CE Delft (2011). This source allows differentiation between different vessel types and load categories. In addition, we use the emission reduction factors reported by Brons and Christidis (2013, Table 6) to produce unit cost values for alternative fuel technologies.

The results in Table 23 are differentiated with respect to vessel capacity as used by CE Delft (2011) as well as with respect to load type: average cargo (i.e. food products, wood, paper, plastics, chemicals, metal products, oil, coals, cokes, waste) and heavy cargo (ores, minerals, metals, sand, stones).

Table 23: Marginal air pollution costs (2010) for inland water transport, EU average, € per 1000 tkm.

		Freight capacity (tonnes)						
		Motor vessels and barges				Pushed convoys		
Fuel technology	**Load type**	**250-400**	**400-650**	**650-1000**	**1000-3000**	**3000-6400**	**6400-12000**	**9600-18000**
Low sulphur oil	bulk, tanker	5.7	5.7	5.8	4.4	4.2	2.8	2.2
	heavy bulk	5.4	5.4	5.5	4.2	4.1	3.0	1.8
Diesel particulate filter (DPF)	bulk, tanker	5.4	5.4	5.6	4.2	4.0	2.7	2.1
	heavy bulk	5.2	5.2	5.3	4.0	3.9	2.9	1.7
Selective catalytic reduction (SCR)	bulk, tanker	1.4	1.4	1.5	1.1	1.1	0.7	0.6
	heavy bulk	1.4	1.4	1.4	1.1	1.0	0.8	0.5
DFP+SCR	bulk, tanker	1.1	1.1	1.1	0.9	0.8	0.5	0.4
	heavy bulk	1.1	1.1	1.1	0.8	0.8	0.6	0.4
LNG	bulk, tanker	1.5	1.5	1.5	1.1	1.1	0.7	0.6
	heavy bulk	1.4	1.4	1.4	1.1	1.1	0.8	0.5
Average load factor, tonnes	bulk, tanker	158	248	608	1356	2475	6240	9009
	heavy bulk	189	297	729	1627	2970	7020	10530

Source: own calculations using emission factors from CE Delft (2011) and emission reduction factors from Brons and Christidis (2013). Damage cost factors (non-urban) from Table 15.

Table 24: Marginal air pollution costs (2010) for inland water transport, EU average, € per ship-km.

Fuel technology	Load type	Freight capacity (tonnes)						
		Motor vessels and barges				Pushed convoys		
		250-400	400-650	650-1000	1000-3000	3000-6400	6400-12000	9600-18000
Low sulphur oil	bulk, tanker	0.9	1.4	3.5	5.9	10.4	17.3	19.6
	heavy bulk	1.0	1.6	4.0	6.9	12.2	21.2	19.0
Diesel particulate filter (DPF)	bulk, tanker	0.9	1.4	3.4	5.6	10.0	16.6	18.8
	heavy bulk	1.0	1.5	3.9	6.6	11.7	20.3	18.2
Selective catalytic reduction (SCR)	bulk, tanker	0.2	0.4	0.9	1.5	2.6	4.4	5.0
	heavy bulk	0.3	0.4	1.0	1.7	3.1	5.3	4.8
DPF+SCR	bulk, tanker	0.2	0.3	0.7	1.2	2.1	3.4	3.9
	heavy bulk	0.2	0.3	0.8	1.4	2.4	4.2	3.7
LNG	bulk, tanker	0.2	0.4	0.9	1.5	2.7	4.4	5.0
	heavy bulk	0.3	0.4	1.0	1.8	3.1	5.4	4.8
Average load factor, tonnes	bulk, tanker	158	248	608	1356	2475	6240	9009
	heavy bulk	189	297	729	1627	2970	7020	10530

Source: own calculations using emission factors from CE Delft (2011) and emission reduction factors from Brons and Christidis (2013). Damage cost factors (non-urban) from Table 15.

4.2.2.4 Maritime transport

Table 25 and Table 26 report unit cost values for maritime transport. The types of vessels and the corresponding emission factors are taken from CE Delft (2011). It is important to note that some important vessel categories are not included (e.g. Ro-Ro, container ships due to a lack of comprehensive data in a consistent format. The damage costs presented below are differentiated by sea area according to damage costs reported in Table 16.

Table 25: Marginal air pollution costs (2010) for maritime transport (average load), EU average, € per 1000 tkm.

Type of ship	Average load, tonnes	Marginal air pollution cost, € per 1000 tkm				
		Baltic Sea	Black Sea	Mediterranean Sea	North Sea	Remaining North-East Atlantic
Crude oil tanker 0-10 kt	1761	4.94	5.22	3.02	6.70	2.37
Crude oil tanker 10-60 kt	18413	1.45	1.55	0.91	1.99	0.70
Crude oil tanker 80-120 kt	49633	0.95	1.01	0.59	1.29	0.45
Products tanker 0-5 kt	810	6.71	7.07	4.09	9.09	3.22
Products tanker 5-10 kt	3150	4.36	4.59	2.65	5.91	2.09
General Cargo 0-5 kt	1527	2.57	2.73	1.59	3.49	1.23
General Cargo 5-10 kt	4174	2.90	3.08	1.81	3.94	1.39
Bulk carrier (feeder)	1440	4.71	5.01	2.93	6.41	2.26
Bulk carrier (handysize)	14300	1.39	1.48	0.87	1.89	0.67
Bulk carrier (handymax)	24750	1.01	1.08	0.63	1.38	0.48

Source: own calculations using emission factors from CE Delft (2011). Damage cost factors (non-urban) from Table 16.

Table 26: Marginal air pollution costs (2010) for maritime transport (average load), EU average, € per ship-km.

Type of ship	Average load, tonnes	Marginal air pollution cost, € per 1000 tkm				
		Baltic Sea	Black Sea	Mediterranean Sea	North Sea	Remaining North-East Atlantic
Crude oil tanker 0-10 kt	1761	8.70	9.19	5.33	11.81	4.17
Crude oil tanker 10-60 kt	18413	26.78	28.60	16.83	36.55	12.83
Crude oil tanker 80-120 kt	49633	46.93	50.03	29.38	63.98	22.49
Products tanker 0-5 kt	810	5.43	5.72	3.31	7.37	2.61
Products tanker 5-10 kt	3150	13.73	14.45	8.35	18.63	6.57
General Cargo 0-5 kt	1527	3.92	4.16	2.43	5.33	1.88
General Cargo 5-10 kt	4174	12.09	12.87	7.55	16.46	5.79
Bulk carrier (feeder)	1440	6.78	7.21	4.22	9.23	3.25
Bulk carrier (handysize)	14300	19.86	21.18	12.44	27.06	9.52
Bulk carrier (handymax)	24750	25.03	26.72	15.71	34.14	12.00

Source: own calculations using emission factors from CE Delft (2011). Damage cost factors (non-urban) from Table 16.

5. Noise costs

5.1 Methodological developments and new data sources

Noise emissions from traffic pose an environmental problem of growing importance. Noise exposure is not only a disutility in the sense that it disturbs people; it can also result in health impairments and lost productivity and leisure. The reason the problem is growing is a combined effect from greater urbanisation and an increase in traffic volume. Whereas the increase in traffic volume means higher noise levels, the urbanisation has led to more individuals being exposed to traffic noise.

Two major impacts are usually considered when assessing noise impacts:

- Annoyance, reflecting the disturbance which individuals experience when exposed to (traffic) noise.
- Health impacts, related to the long term exposure to noise, mainly stress related health effects like hypertension and myocardial infarction.

It can be assumed that these two effects are independent, i.e. the potential long term health risk is not taken into account in people's perceived noise annoyance.

The most accurate methodology available for the estimation of marginal noise costs is similar to the approach for the air pollution costs, namely the Impact Pathway Approach (IPA). Navrud (2002) defines the following steps of the IPA for noise.

Table 27: Impact Pathway Approach for noise

Step	Description
Noise Emissions	The changed levels of noise are measured in terms of change in time, location, frequency, level and source of noise.
Noise Dispersion	The differences in exposure to noise are estimated according to geographical locations, and measured in dB (A) and noise level indicators (L_{den} and L_{night}). The results are presented in noise maps.
Exposure-Response Functions	These functions present a relationship between decibel levels and negative impacts of noise. Each impact has one or more endpoints. Using the information about the number of cases of each endpoint, the overall change in noise impact is calculated.
Economic Valuation	An economic value for a unit of each endpoint of the exposure-response functions is calculated either by transferring estimates from existing valuation studies or by conducting a new original study using environmental valuation techniques.
Overall assessment	Economic value of each unit of endpoint is multiplied by the corresponding impact and aggregated over all endpoints from exposure-response functions.

Most attention in the recent studies has been specifically devoted to the quantification of damage costs of noise (step 4 in the above Table 27). A HEIMTSA review (Máca et al. (2008)) shows relatively unambiguous situation with respect to preferable valuation method for noise effects. While to date most policy applications are based on hedonic price studies, recent advances in stated preference approach provide a solid basis for wider use of (health) endpoint specific estimates. This is also in line with the continuous effort to derive exposure-response functions for particular health effects caused by noise exposure. Building on these new pieces of knowledge, it is suggested that specific estimates for respective endpoints are used, including annoyance, sleep disturbance, acute myocardial infarction and hypertension. Unfortunately, the review by Máca et al. (2008) does not provide marginal cost estimates based on these updated values for various health endpoints. Therefore, the recommended unit costs below are based on an older source. The mentioned review should however be used by any new studies performing all the steps of calculations in the impact pathway approach.

Another important development over the last years has been the compilation of the NOISE database (ETC/LUSI (2013)) on exposure to different sources of transport noise. The data is regularly provided by Member States under the frame of the Environmental Noise Directive. These data can be used to calculate noise costs in a top-down manner, namely starting from the estimated number of people affected by certain type of noise and then distributing these costs to different vehicles using a certain weighting scheme.

As described in the 2008 Handbook, such a top-down approach provides estimates for average noise costs. In contrast, a bottom-up approach (IPA) described in Table 27 provides marginal noise costs. The 2008 Handbook describes the pros and cons of the two methods. The bottom-up method in general produces very specific results that differ substantially between types of areas, time of the day, type of traffic situation, etc. As a consequence, these are hard to generalise for the whole EU. On the other hand, the top-down method tends to average out many local characteristics in the estimates, which might in fact be an advantage from the point of view of practical use for the internalisation of external costs.

Due to the lack of comparable country-level data on noise exposure, the 2008 Handbook based its recommendations for road transport on the marginal cost estimates by INFRAS/IWW (2004), which, by design of model scenarios, can be regarded as representing averaged values for the EU for specific situations.

New studies providing estimates of marginal noise costs are very few and generally built on the earlier studies already covered in the 2008 Handbook. Recent estimates for Sweden are reported by Andersson and Ögren (2009). There, the average noise costs for heavy vehicles are estimated in the order of 1.2-1.6 eurocent per vkm. Haraldsson et al. (2012) provide the most recent estimates for Denmark, which are differentiated by traffic density on the road and population density in the road vicinity. The highest noise costs corresponding to the least favourable combination of the two is relevant for roughly 0.1% of total traffic and is in the order of 8 eurocent per km. For 99% of traffic, the noise costs do not exceed 1 eurocent per vkm.

5.2 Updated unit values for noise costs

5.2.1 Road and rail transport

The review of the recent literature did not reveal a new source of bottom-up estimates of marginal noise costs that could be preferred to the values used in the 2008 Handbook and updated by CE Delft et al. (2011). Therefore, it is recommended to keep these values, updated for the changed overall price levels in the EU. Table 28 documents the relevant values.

Table 28: Illustrative marginal noise costs for the EU*, € per 1000 vkm

Mode	Time of day	Traffic type	Urban	Suburban	Rural
Car	Day	Dense	8.8	0.5	0.1
		Thin	21.4	1.4	0.2
	Night	Dense	16.1	0.9	0.1
		Thin	38.9	2.5	0.4
Motorcycle	Day	Dense	17.7	1.1	0.1
		Thin	42.7	2.7	0.4
	Night	Dense	32.1	1.9	0.2
		Thin	77.9	5.1	0.6
Bus	Day	Dense	44.0	2.4	0.4
		Thin	107.0	6.8	0.8
	Night	Dense	80.3	4.5	0.7
		Thin	194.7	12.7	1.5
LCV	Day	Dense	44.0	2.4	0.4
		Thin	107.0	6.8	0.8
	Night	Dense	80.3	4.5	0.7
		Thin	194.7	12.7	1.5
HGV	Day	Dense	81.0	4.5	0.7
		Thin	196.6	12.7	1.5
	Night	Dense	147.8	8.3	1.3
		Thin	358.2	23.1	2.6
Passenger train	Day	Dense	273.4	12.1	15.0
		Thin	540.2	23.8	29.7
	Night		901.6	39.8	49.6
Freight train	Day	Dense	484.8	23.9	29.9
		Thin	1,169.6	46.3	57.8
	Night		1,977.6	78.3	97.7

Source: Values from CE Delft et al. (2011), updated to price level of 2010.

Note: Area and traffic density types are defined by specific assumptions on traffic volume, share of freight transport, distance to road or track, population density, etc. Urban areas: population density of 3000 inhabitants per km of road length; suburban areas: population density of 700 inhabitants per km of road length; rural areas: population density of 500 inhabitants per km of road length. See Annex D2 and D3 for further details.

** Country-specific values are provided in Excel tables as Annexes to this report.*

The values for road noise are calculated based on a bottom-up noise exposure model from the German directive for road noise protection (RLS-90: Richtlinien für den Lärmschutz an Straßen). The values for rail traffic are based on the STAIRRS (2002) model. Tables D-1 and D-2 in Annex D (kindly provided by the authors of the 2008 Handbook) present the major parameters used to calculate the unit values in Table 28.

Since the data for rail does not include values for urban areas, the respective marginal cost values were estimated in the 2008 Handbook by using the ratio between the marginal rail noise costs in interurban and urban areas from INFRAS/IWW (2004).

It is also worthwhile to illustrate the results of a top-down approach. Compared to the calculations in the 2008 Handbook, one can make use of the noise exposure data from the NOISE database (ETC/LUSI (2013)), as well as of the more recent version of the TREMOVE database containing transport flow data.

The NOISE database reports, for different noise bands, the number of people exposed to noise from major roads in all EU Member States. The major roads (motorways, trunk and classified roads) are defined by a threshold of 3 million vehicle passages per year. The major roads inside and outside agglomerations are treated separately. The reported length of major roads in some Member States (e.g. Germany, Denmark, Finland, Italy) is very close to the total length of motorways as documented, e.g. by Eurostat. The data available for download in July 2013 is not yet final, and some errors in the data can be identified. An illustration is provided below, by calculating average noise costs for German motorways. The necessary data and calculation steps are described in Annex D.

The noise exposure data have to be combined with the cost factors for different noise bands. These cost factors stem from HEATCO (2006) and are the same as in the 2008 Handbook, except for the update of the price level (using GDP per capita values). The total noise costs for German motorways (outside agglomerations) amount to €250 million per year. When distributed across different vehicle categories using the traffic flow data from TREMOVE v.3.2.2, this corresponds to the unit costs in Table 29.

Table 29: Illustrative average noise costs for German motorways, €ct (2010) per vkm

Vehicle type	Unit cost
Car	0.15
Motorcycle	0.61
LCV	0.18
Bus	0.48
HGV < 16t	0.44
HGV > 16t	0.61

Source: Own calculations, based on ETC/LUSI (2013) and HEATCO (2006).

Due to substantial methodological differences, the values in Table 28 and Table 29 are not comparable. Overall, it can however be concluded that the noise costs outside agglomerations are likely to not exceed 1 eurocent per vkm even for heavy trucks.

5.2.2 Air transport

For air transport, the marginal noise cost estimates are normally available from airport case studies and thus the values differ substantially between each other. CE Delft et al. (2011) therefore recommend deriving a plausible range for the marginal costs from the average cost figures.

The NOISE database reports the number of people exposed to noise from major European airports (separately, for exposed population outside agglomerations, and all exposed population) as well as the associated number of commercial passenger aircraft movements. By applying the cost factors from HEATCO (2006) to the number of people exposed to noise, it is thus possible to derive the total cost as well as the average cost figures for a sample of major airports. It is however not possible to further differentiate these values by aircraft type.

From the airport-specific figures it can be clearly concluded that the population density around airports is an important driver of noise costs. The cost figures for city airports, such as Berlin Tegel, are by an order of magnitude larger than the cost figures for airports located outside urban areas.

Table 30: Average noise costs of major airports, € (2010) per LTO.

Country	Airport	Population outside agglomerations	All population exposed to noise
Austria	Vienna International Airport	10.8	14.8
Belgium	Brussels National Airport	59.1	76.9
Czech Republic	Prague Ruzyně International Airport	3.3	4.2
Denmark	Billund Airport	0.7	0.9
Denmark	Roskilde Airport	0.5	0.7
Denmark	Copenhagen Airport	1.2	5.8

Country	Airport	Population outside agglomerations	All population exposed to noise
Finland	Helsinki Vantaa Airport	0.1	0.2
France	Lyon Saint Exupery Airport	7.3	10.5
France	Paris Charles de Gaulle Airport	66.3	110.6
France	Paris Orly Airport	2.8	221.3
France	EuroAirport Basel-Mulhouse-Freiburg	2.4	3.5
Germany	Hannover Langenhagen Airport	95.7	115.8
Germany	Nürnberg Airport	5.1	57.8
Germany	Stuttgart Airport	78.1	101.3
Germany	Munich International Airport	5.9	7.6
Germany	Hamburg Airport	96.2	124.1
Germany	Frankfurt am Main Airport	136.3	180.7
Germany	Berlin Tegel Airport		702.2
Greece	Athens International Airport	11.0	0.0
Hungary	Budapest Ferihegy International Airport	12.0	259.6
Italy	Bergamo Orio al Serio Airport	182.8	234.3
Italy	Milan Linate Airport	187.7	233.3
Italy	Milan Malpensa International Airport	36.2	43.8
Italy	Naples International Airport	85.2	385.5
Italy	Roma Fiumicino - Leonardo da Vinci Airport	26.9	34.9
Italy	Turin International Airport	32.7	50.7
Luxembourg	Luxembourg International Airport	249.3	284.9
Netherlands	Amsterdam Schipol Airport	0.6	38.8
Poland	Warszaw F.Chopin Airport	4.1	27.1
Portugal	Lisbon Airport	5.9	205.3
Spain	Gran Canaria Airport	8.2	10.2
Spain	Madrid Barajas Airport	19.7	28.3
Spain	Málaga Airport	1.4	17.2
Spain	Alicante Airport	23.7	37.9
Spain	Barcelona International Airport	5.1	6.5
Spain	Tenerife Sur Airport	33.4	46.6
Spain	Palma de Mallorca Airport	0.1	16.8
Spain	Tenerife Norte Airport	71.3	90.8
Spain	Bilbao Airport	44.6	53.7
Spain	València Airport	100.7	170.4
Sweden	Göteborg-Landvetter Airport	1.6	1.9
Sweden	Stockholm-Arlanda Airport	1.7	2.4
United Kingdom	London Stansted Airport	14.8	19.6
United Kingdom	Southampton Airport	0.5	82.3
United Kingdom	Aberdeen Airport	52.9	66.4
United Kingdom	Edinburgh Airport	19.5	39.4
United Kingdom	Glasgow Prestwick International Airport	33.1	37.2
United Kingdom	Newcastle Airport	23.1	28.6
United Kingdom	London Luton Airport	28.4	35.0
United Kingdom	Leeds Bradford International Airport	0.5	59.1
United Kingdom	London Gatwick Airport	15.2	19.3
United Kingdom	Liverpool John Lennon Airport	12.8	26.5
United Kingdom	Birmingham International Airport	2.0	160.9
United Kingdom	Bournemouth Airport	2.4	17.2
United Kingdom	Bristol International Airport	15.3	19.5
United Kingdom	Nottingham East Midlands Airport	44.3	59.6

Country	Airport	Population outside agglomerations	All population exposed to noise
United Kingdom	Manchester International Airport	15.2	169.3
United Kingdom	Belfast International Airport	3.1	4.0
United Kingdom	London Heathrow Airport	70.6	652.1

Source: Own calculations based on ETC/LUSI (2013) and HEATCO (2006).

Following the approach of CE Delft et al. (2011), a range for marginal costs for air transport would correspond to 30%-60% of the corresponding average costs.

For illustrative purposes we also include the marginal cost estimates from several airport case studies already reported in the Handbook-2008. They provide differentiated values for different aircraft types.

Table 31: Marginal noise costs at Frankfurt airport, € (2000) per LTO.

Aircraft type	07L (easterly traffic)			25R (westerly traffic)		
	Day	Evening	Night	Day	Evening	Night
737-800	32.4	77.0	240.8	29.0	69.0	216.4
747-200	71.6	170.0	524.0	55.8	132.4	412.6
747-400	128.0	304.0	934.0	113.6	269.4	836.6
767-300	42.6	101.2	316.0	34.6	82.0	257.2
A 300-62	77.8	184.6	572.0	76.6	181.6	567.8
A 319	14.6	34.4	108.8	12.8	30.6	96.6
A 320	26.0	61.8	194.4	23.2	54.8	193.0
A 340	51.6	122.4	385.8	54.0	127.8	403.4
ATR 72	7.2	17.2	53.8	1.6	3.8	11.8
DHC 8	2.6	6.2	19.6	0.2	0.4	1.4
EMB 145	7.0	16.6	52.0	2.2	5.2	16.2
MD 82	9.2	21.8	68.6	3.4	8.2	26.2

Source: Ökoinstitut/DIW (2004).

Table 32: Marginal noise costs at Heathrow London airport, € (2000) per LTO.

Aircraft type	€ per LTO
A210	92.3
A340	111
Bae146	21.6
B737-100	326
B737-400	49.1
B747-400	242
B757	63.5
B767-300	77.9
B777	47.6
F100	17.3
MD82	70.7

Source: TRL (2001).

Another important factor explaining the wide ranges in marginal noise costs estimates for aviation is thus the aircraft type. Öko-institut/DIW (2004) show that noise costs can differ by a factor 700 between various aircraft types.

6. Climate change costs

6.1 Methodological developments and new data sources

6.1.1 Overview of recent studies

Climate change induced by worldwide greenhouse gas (GHG) emissions is currently one of the key topics of global research output. The climate models and the connected economic impact assessment models are being continuously improved and results of new scenarios are made public. The central question of impact assessment is the realistic evaluation of the carbon price, which is envisioned as the main instrument of the future global climate policy.

The unit cost estimation for different transport modes follows a procedure that is already familiar from the discussion of air pollution and noise costs, namely the Impact Pathway Approach. It encompasses the following steps:

1. Quantification of GHG emission factors for different vehicles, expressed in tonnes CO_2 equivalent per vkm.
2. Valuation of climate change costs per tonne of CO_2 equivalent.
3. Calculation of marginal climate change costs for different vehicle (and fuel) types.

The steps of dispersion and exposure analysis, which were included in Figure 2 are skipped in this case, as global warming potentials of different greenhouse gases are well studied and there exists scientific consensus on their relative values. The key methodological step is, however, the valuation of climate change costs.

In general, there are two main approaches to the evaluation of the cost of GHG emissions. The first is the **damage cost approach**, which can intuitively be explained as an evaluation of total costs under the assumption that no efforts are taken to reduce the pace of climate change. It implies the incorporation of various effects connected to changes in sea level, landscape, fresh water availability, vegetation, etc. The second is the **abatement cost approach**, which evaluates the cost of achieving a given amount of emissions reduction.

The estimation of full damage costs, although desirable from a scientific point of view (as it allows quantifying the external effects fully), is connected with extremely high uncertainty due to complex global pathways of various effects and long-time horizons involved. On the other hand, the use of abatement cost figures is a theoretically sound alternative, if the emission reduction targets adequately reflect the preferences of society and can thus be used in the context of determination of willingness-to-pay for a certain abatement level. Another argument for using avoidance cost estimates is the fact that many risks connected with future climate change cannot yet be identified and evaluated. For these reasons (also discussed in CE Delft et al. (2011)), the calculations of climate change costs below are based on the estimates of CO_2 costs derived from an abatement cost approach. The results of the damage cost approach are included in Annex E.

Most single model applications that concentrate on various aspects of climate cost valuation are done using several famous models: FUND (e.g. Anthoff et al. (2011)), DICE (e.g. Ackerman and Stanton (2012)), and PAGE (e.g. Hope (2011b)). Due to substantial differences in cost estimates of different studies (related to the choice of an inter-temporal discount rate, and fossil fuel price forecast), it however seems reasonable to base the calculations on a certain average, or even better - on a plausible range of values.

A meta-study by Kuik et al. (2009) is based on a wide range (26 models) of available estimates of abatement costs. This study is used as a source of avoidance cost figures in the recent overviews by CE Delft et al. (2011) and TU Dresden (2012). Due to the nature of this meta-study, which originated from a joint effort of different modellers calculating mutually comparable scenarios, their paper can be considered a reliable source for average estimates.

6.1.2 Update of input values

For the purpose of the calculation of unit climate change costs, it is recommended to use the estimates of avoidance costs corresponding to efforts required to stabilise global warming at 2°C (maximum CO_2 equivalent concentration in the atmosphere of 450 ppm). This is the goal currently supported by the United Nations Framework Convention on Climate Change (UNFCCC).

Kuik et al. (2009) provide the following cost estimates associated with this strict target: €129/t CO_2-eq in 2025 (with a range €69–€241) and €225/t CO_2-eq in 2050 (€128–€396). These values are all measured in 2005 prices.

CE Delft et al. (2011) discount the values for 2025 back to 2008 using a discount rate of 3% p.a., which is a the lower end of the typically used range of discount factors (3-5%). One may argue that in the current economic situation, an even lower discount factor should be used, but in general the value of 3% seems reasonable for the relatively long time horizon until 2025.

Using the discount factor of 3%, and converting from 2005 prices to 2010 prices using the Eurozone inflation rate (GDP deflator), we arrive at the range of values to be used in the calculations below: €48 - €168, with a central value €90.

This valuation of current GHG emissions matches well enough with some other reviews. UBA (2012) in the methodological guidelines for Germany suggests a central value of €80 with a range €40-€120 (all in prices of 2010). Watkiss and Downing (2008) report £80 as the central value for 2010 of the social cost of carbon as used in UK policy appraisal.

The update of the central value of the carbon price to €90 is a substantial change in comparison to the Handbook-2008, where the value of €25 was used. Given the uncertainty linked to the process of estimation of the carbon price, it might well be that this value will have to be revised again relatively soon. An update of the corresponding unit costs provided below, however, would be very easy, as all values would only need to be multiplied by the factor (New carbon price estimate)/(€90).

The sources of CO_2 emission factors are the same as for the air pollutants. The EEA/EMEP guidelines provide detailed information for different vehicle, fuel, and engine types. TREMOVE v.3.3.2 database is a reliable source of more aggregate and ready-to-use data.

The TREMOVE average emission factors for EU-27 in 2010 are given in Table 33 below. The GHG considered and added together are CO_2 (global warming potential = 1), CH_4 (global warming potential = 25) and N_2O (global warming potential = 298)[15].

[15] Source for GWP factors: IPCC 4th Assessment Report, p. 212.

Table 33: TREMOVE average GHG emission factors, in gram CO_2 eq /vkm

Vehicle category	Diesel	CNG	Gasoline	LPG	All fuel types
Bus	676	528			670
Car	179	159	197	182	189
Light commercial vehicle	218		278		228
HGV 3.5-7.5 t	312				312
HGV 7.5-16 t	534				534
HGV 16-32 t	715				715
HGV > 32 t	906				906
Moped			59		59
Motorcycle			104		104
Freight train (diesel)	11473				11473
Passenger train (diesel)	5723				5723
Plane (kerosene)					1103
Inland ship (ship gasoil)					12609
Maritime general cargo ship (ship fuel oil)					24432

Sources: TREMOVE v.3.3.2 (all transport modes except maritime shipping) and CE Delft (2011) (only for maritime shipping).

6.2 Updated unit climate change costs

The GHG emission factors from typical fuel types are well documented in the literature. These can be used to calculate climate change costs per unit of fuel consumption.

Table 34: Climate change costs per unit of fuel consumption, prices of 2010.

Fuel	kg CO_2 per litre of fuel	g CH_4 per litre of fuel	g N_2O per litre of fuel	Climate change cost, €ct per litre of fuel
Gasoline	2.25	0.81	0.26	21.1
Diesel (road and rail)	2.66	0.14	0.14	24.3
Marine diesel oil	2.99	0.27	0.08	27.2
Jet kerosene	2.86	0.02	0.08	26.0
LPG (50% propane + 50% butane)	1.77	1.74	0.01	16.3
CNG (methane)	1.57	2.58	0.08	14.9

Source of emission factors: IPCC Guidelines for National Greenhouse Gas Inventories (Chapter 3).
Climate costs evaluated at central value for CO2 eq.: €90/tonne.

The marginal climate change costs for different vehicle types and transport modes are produced by multiplying the emission factors (CO_2 equivalent) extracted from the TREMOVE database by the carbon price. The definition of area and road types is the same as in Chapter 4 on air pollution costs, but the damage cost factor (carbon price) is the same for all areas.

Table 35: Marginal climate change costs for road transport (cars and light commercial vehicles), EU average (prices of 2010).

Vehicle	Size	EURO-Class	Urban	Rural	Motorways	Average
			(€ct/vkm)	(€ct/vkm)	(€ct/vkm)	(€ct/vkm)
Passenger Car - Petrol	<1,4L	EURO-0	2.8	1.7	1.8	2.0
		EURO-1	2.6	1.5	1.7	1.8
		EURO-2	2.5	1.4	1.5	1.7
		EURO-3	2.4	1.4	1.5	1.7
		EURO-4	2.4	1.4	1.5	1.7
		EURO-5	2.4	1.4	1.5	1.7
	1,4-2L	EURO-0	3.4	2.0	2.1	2.3
		EURO-1	3.1	1.8	1.9	2.1
		EURO-2	3.0	1.7	1.7	2.0
		EURO-3	2.9	1.7	1.7	2.0
		EURO-4	2.9	1.7	1.7	2.0
		EURO-5	2.9	1.7	1.7	2.0
	>2L	EURO-1	3.9	2.3	2.3	2.8
		EURO-2	3.9	2.3	2.3	2.7
		EURO-3	3.5	1.9	1.8	2.4
		EURO-4	3.5	1.9	1.8	2.4
		EURO-5	3.5	1.9	1.8	2.4
Passenger Car - Diesel	<1,4L	EURO-2	1.7	1.1	1.2	1.3
		EURO-3	1.6	1.1	1.2	1.3
		EURO-4	1.6	1.1	1.2	1.3
		EURO-5	1.6	1.1	1.2	1.3
	1,4-2L	EURO-0	2.4	1.7	1.9	1.9
		EURO-1	2.2	1.5	1.8	1.7
		EURO-2	2.2	1.5	1.6	1.7
		EURO-3	2.1	1.4	1.5	1.6
		EURO-4	2.1	1.4	1.5	1.6
		EURO-5	2.1	1.4	1.5	1.6
	>2L	EURO-0	3.3	2.3	2.7	2.6
		EURO-1	3.0	2.1	2.4	2.4
		EURO-2	3.0	2.0	2.3	2.3
		EURO-3	2.9	1.9	2.1	2.2
		EURO-4	2.9	1.9	2.1	2.2
		EURO-5	2.9	1.9	2.1	2.2
Light commercial vehicles	Petrol	EURO-0	4.0	2.5	2.8	2.7
		EURO-1	3.6	2.3	2.5	2.5
		EURO-2	3.7	2.2	2.4	2.5
		EURO-3	3.7	2.2	2.4	2.5
		EURO-4	3.4	2.1	2.3	2.3
		EURO-5	3.4	2.1	2.3	2.3
	Diesel	EURO-0	2.9	2.0	2.9	2.4
		EURO-1	2.8	1.8	2.6	2.2
		EURO-2	2.8	1.8	2.6	2.2
		EURO-3	2.8	1.8	2.5	2.1
		EURO-4	2.8	1.7	2.4	2.1
		EURO-5	2.8	1.7	2.4	2.1

Source emission factors: TREMOVE v.3.3.2, evaluated at the central value for CO2: €90/tonne. Area definition according to TREMOVE database (de Ceuster et al., 2006, p. 124).
Note: Urban roads - roads inside urban settlement areas; motorways - non-urban motorways with separated lanes and central barrier; rural - other roads outside urban settlement areas.

Table 36: Marginal climate change costs for road transport (buses and HGVs), EU average (prices of 2010).

Vehicle	Type	EURO-Class	Urban	Rural	Motorways	Average
			(€ct/vkm)	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*
Buses		EURO-I	7.7	5.8	5.3	6.3
		EURO-II	7.6	5.6	5.1	6.1
		EURO-III	7.6	5.6	5.1	6.1
		EURO-IV	7.4	5.1	4.6	5.8
		EURO-V	7.4	5.1	4.6	5.8
HGVs	<7.5t	EURO-0	3.8	3.2	3.4	3.4
		EURO-I	3.1	2.7	3.0	2.9
		EURO-II	2.9	2.5	2.8	2.7
		EURO-III	2.9	2.6	2.8	2.7
		EURO-IV	2.7	2.3	2.5	2.5
		EURO-V	2.7	2.3	2.5	2.5
	7.5-16t	EURO-0	6.5	5.4	5.1	5.6
		EURO-I	5.7	4.7	4.5	5.0
		EURO-II	5.5	4.4	4.2	4.7
		EURO-III	5.7	4.3	4.2	4.8
		EURO-IV	5.3	3.9	3.7	4.4
		EURO-V	5.3	3.9	3.7	4.4
	16-32t	EURO-0	10.6	8.3	7.3	8.5
		EURO-I	9.7	7.7	6.8	8.0
		EURO-II	9.4	7.4	6.4	7.8
		EURO-III	9.7	7.2	6.2	7.6
		EURO-IV	8.9	6.5	5.5	7.0
		EURO-V	8.9	6.5	5.5	7.0
	>32t	EURO-0	13.2	10.4	9.0	10.4
		EURO-I	12.1	9.6	8.2	9.5
		EURO-II	11.9	9.3	7.9	9.3
		EURO-III	12.1	9.0	7.5	9.1
		EURO-IV	11.2	8.1	6.7	8.3
		EURO-V	11.2	8.0	6.7	8.3

Source emission factors: TREMOVE v.3.3.2, evaluated at the central value for CO2: €90/tonne. Area definition according to TREMOVE database (de Ceuster et al., 2006, p. 124).
Note: Urban roads - roads inside urban settlement areas; motorways - non-urban motorways with separated lanes and central barrier; rural - other roads outside urban settlement areas. Definition of urban area is country-specific (more than 50,000 inhabitants, in most cases).

Table 37: Marginal climate change costs for diesel trains, EU average (prices of 2010).

Type of train		Urban			Non-urban		
		Unit cost		Load factor	Unit cost		Load factor
		€ct/ pkm €ct/ tkm	*€ct/ train-km*	*pax or tonne*	*€ct/ pkm €ct/ tkm*	*€ct/ train-km*	*pax or tonne*
Passenger	Locomotive	0.45	56.30	125	0.39	62.08	159
	Railcar (multiple unit)	0.33	39.88	120	0.35	42.03	120
Freight	Locomotive	0.26	126.31	500	0.26	126.31	500

Source emission factors: TREMOVE v.3.3.2, evaluated at the central value for CO2: €90/tonne.

Note: Values for railcars are for a complete train composed of multiple railcar units. Area definition is according to those used in the TREMOVE database. Urban - rail network inside urban settlement areas; non-urban - rail network outside urban settlement areas. Definition of urban area is country-specific (more than 50000 inhabitants, in most cases).

Table 38: Marginal climate change costs for air transport, EU average (prices of 2010).

Flight distance	Climate cost		Load factor
	€ct/pkm	€/flight	pax
<500 km	2.22	465	80
500-1,000 km	1.66	996	80
1,000-1,500 km	1.25	1912	120
1,500-2,000 km	1.20	2894	140
>2,000 km	1.25	13308	220

Source emission factors: TREMOVE v.3.3.2, evaluated at the central value for CO2: €90/tonne.

Table 39: Marginal climate change costs for inland waterway transport, EU average (prices of 2010), € per 1000 tkm.

Fuel technology	Load type	Freight capacity (tonnes)						
		Motor vessels and barges				Pushed convoys		
		250-400	400-650	650-1000	1000-3000	3000-6400	6400-12000	9600-18000
Low sulphur oil	bulk, tanker	3.1	3.1	3.1	2.3	2.3	1.4	1.2
	heavy bulk	2.9	2.9	3.0	2.2	2.2	1.5	1.2
Diesel particulate filter (DPF)	bulk, tanker	3.1	3.1	3.1	2.3	2.3	1.5	1.2
	heavy bulk	2.9	2.9	3.0	2.2	2.2	1.6	1.2
Selective catalytic reduction (SCR)	bulk, tanker	3.1	3.1	3.1	2.3	2.3	1.4	1.2
	heavy bulk	2.9	2.9	3.0	2.2	2.2	1.5	1.2
DFP+SCR	bulk, tanker	3.1	3.1	3.1	2.3	2.3	1.5	1.2
	heavy bulk	2.9	2.9	3.0	2.2	2.2	1.6	1.2
LNG	bulk, tanker	2.8	2.8	2.8	2.0	2.0	1.3	1.1
	heavy bulk	2.6	2.6	2.7	1.9	1.9	1.4	1.1
Average load factor, tonnes	bulk, tanker	158	248	608	1356	2475	6240	9009
	heavy bulk	189	297	729	1627	2970	7020	10530

Source emission factors: CE Delft (2011), evaluated at the central value for CO2: €90/tonne.

Table 40: Marginal climate change costs for short sea shipping, EU average (prices of 2010), € per 1000 tkm.

Type of ship	Average load, tonnes	European sea area				
		Baltic Sea	Black Sea	Mediterra-nean Sea	North Sea	Remaining North-East Atlantic
Crude oil tanker 0-10 kt	1761	3.1	3.1	3.1	3.1	3.1
Crude oil tanker 10-60 kt	18413	0.8	0.8	0.8	0.8	0.8
Crude oil tanker 80-120 kt	49633	0.5	0.5	0.5	0.5	0.5
Products tanker 0-5 kt	810	4.1	4.1	4.1	4.1	4.1
Products tanker 5-10 kt	3150	2.7	2.7	2.7	2.7	2.7
General Cargo 0-5 kt	1527	1.4	1.4	1.4	1.4	1.4
General Cargo 5-10 kt	4174	1.5	1.5	1.5	1.5	1.5
Bulk carrier (feeder)	1440	2.7	2.7	2.7	2.7	2.7
Bulk carrier (handysize)	14300	0.7	0.7	0.7	0.7	0.7
Bulk carrier (handymax)	24750	0.5	0.5	0.5	0.5	0.5

Source: Marco Polo calculator, Brons and Chistidis (2013), evaluated at the central value for CO2: €90/tonne.

7. Costs of up- and downstream processes

This section builds on the 2008 Handbook, with the unit cost values for land transport calculated using updated damage costs of air pollutants (Chapter 4), an updated carbon price (Chapter 6), and TREMOVE emission factors. Own literature review has been conducted for the costs of inland waterway transport.

Indirect effects due to the production of energy, vehicles and transport infrastructure cause additional external costs. It has to be considered that these costs occur in other markets as well as the transport market (e.g. energy market). Thus it is important to consider the level of internalisation within these markets. The most relevant processes are the following:

- Energy production (pre-combustion): The production of all types of energy causes additional nuisances due to extraction, transport, and transmission. These impacts depend directly on the amount of energy used. A critical issue is the production of electricity for the railway sector based on different types of energy sources (renewable and non-renewable). Whereas the air pollution related costs are shown in Chapter 2, there are additional costs to consider (well-to-tank emissions).
- Vehicle production, maintenance and disposal: The production, maintenance and disposal of vehicles and rolling stock causes environmental effects (emission of air, water, soil pollutants, greenhouse gases, etc.) during a long period, considering the life cycles of different transport means.
- Infrastructure construction, maintenance and disposal: The construction, maintenance and disposal of infrastructure elements also lead to negative environmental effects (emission of pollutants).

7.1 Methodological approach

The methodology for the calculation of up- and downstream processes is virtually the same in all studies quantifying these costs: The costs are calculated the same way as the direct external cost categories of transport operations, mainly based on additional air pollution and climate change costs. The main difference between the studies is the different kinds of cost categories (effects) covered: some studies only cover climate change costs of up- and downstream processes whereas others also cover air pollution costs and costs due to nuclear power risks. (INFRAS/IWW, 2000/2004a; ExternE, 1999; NewExt, 2004; Friedrich and Bickel, 2001; OSD, 2006).

7.1.1 Input values

The most important input values are the total emissions of up- and downstream processes (e.g. emissions of CO_2, CH_4, N_2O, PM, NO_x, SO_2, etc.). The type of pollutant for which emission data is needed depends on the cost categories covered (e.g. for calculating the climate change costs, the emitted amount of CO_2 and other greenhouse gases needs to be known). Emission factors can be found in the EMEP/EEA Guidebooks or calculated at a more aggregate level using the TREMOVE database.

Regarding the valuation, damage cost factors or shadow prices of the corresponding cost categories are necessary: costs per emitted amount of a pollutant (see corresponding chapters above: Chapter 2 on air pollution costs and Chapter 7 on climate change costs).

7.1.2 Output values for pre-combustion processes

The following tables show the results of the so called pre-combustion processes for road, rail, inland waterways and air transport. Cost figures cover fuel cycle related air pollution and climate change costs based on the TREMOVE v.3.3.2 model.

7.1.2.1 Road transport

Table 41 and Table 42 contain marginal cost values for road transport. The differentiation by area/road type only reflects the differences in speed regimes (fuel consumption), and not the density of the affected population. The damage costs (Table 15) applied here and further are for the non-urban areas, which reflects the more usual location of the oil transport routes, refineries and large power stations.

Table 41: Marginal costs of up- and downstream processes (well-to-tank emission and climate change costs) for cars and light commercial vehicles, EU average (2010).

Vehicle	Size	EURO-Class	Urban	Rural	Motorways	Average
			(€ct/vkm)	*(€ct/vkm)*	*(€ct/vkm)*	*(€ct/vkm)*
Passenger Car Petrol	<1,4L	EURO-0	1.4	0.8	0.9	1.0
		EURO-1	1.2	0.8	0.8	0.9
		EURO-2	1.2	0.7	0.8	0.8
		EURO-3	1.2	0.7	0.8	0.8
		EURO-4	1.2	0.7	0.8	0.8
		EURO-5	1.2	0.7	0.8	0.8
	1,4-2L	EURO-0	1.7	1.0	1.0	1.2
		EURO-1	1.5	0.9	0.9	1.1
		EURO-2	1.5	0.8	0.9	1.0
		EURO-3	1.5	0.8	0.9	1.0
		EURO-4	1.4	0.8	0.9	1.0
		EURO-5	1.4	0.8	0.9	1.0
	>2L	EURO-1	1.9	1.1	1.2	1.4
		EURO-2	1.9	1.1	1.1	1.4
		EURO-3	1.8	1.0	0.9	1.2
		EURO-4	1.8	1.0	0.9	1.2
		EURO-5	1.8	1.0	0.9	1.2
Passenger Car Diesel	<1,4L	EURO-2	0.7	0.5	0.5	0.6
		EURO-3	0.7	0.5	0.5	0.5
		EURO-4	0.7	0.5	0.5	0.5
		EURO-5	0.7	0.5	0.5	0.5
	1,4-2L	EURO-0	1.0	0.7	0.8	0.8
		EURO-1	1.0	0.7	0.8	0.8
		EURO-2	1.0	0.6	0.7	0.7
		EURO-3	0.9	0.6	0.7	0.7
		EURO-4	0.9	0.6	0.7	0.7
		EURO-5	0.9	0.6	0.7	0.7
	>2L	EURO-0	1.5	1.0	1.2	1.1
		EURO-1	1.3	0.9	1.1	1.0
		EURO-2	1.3	0.9	1.0	1.0
		EURO-3	1.2	0.8	0.9	1.0
		EURO-4	1.2	0.8	0.9	1.0
		EURO-5	1.2	0.8	0.9	1.0

Vehicle	Size	EURO-Class	Urban	Rural	Motorways	Average
			(€ct/vkm)	(€ct/vkm)	(€ct/vkm)	(€ct/vkm)
Light commercial vehicle	Petrol	EURO-0	1.9	1.2	1.3	1.3
		EURO-1	1.7	1.1	1.2	1.2
		EURO-2	1.7	1.1	1.2	1.2
		EURO-3	1.7	1.1	1.2	1.2
		EURO-4	1.7	1.1	1.2	1.2
		EURO-5	1.7	1.1	1.2	1.1
	Diesel	EURO-0	1.3	0.9	1.3	1.1
		EURO-1	1.2	0.8	1.2	1.0
		EURO-2	1.2	0.8	1.1	1.0
		EURO-3	1.2	0.8	1.1	0.9
		EURO-4	1.2	0.8	1.1	0.9
		EURO-5	1.2	0.7	1.1	0.9

Source of emission factors: TREMOVE Base Case (model version 3.3.2). Climate costs evaluated with the central value for CO2: €90/tonne. Air pollution damage costs (non-urban) from Table 15.
Note: Area definition according to TREMOVE database (de Ceuster et al., 2006, p. 124). Urban roads - roads inside urban settlement areas; motorways - non-urban motorways with separated lanes and central barrier; rural - other roads outside urban settlement areas. Definition of urban area is country-specific (more than 50000 inhabitants, in most cases).

Table 42: Marginal costs of up- and downstream processes (well-to-tank emission and climate change costs) for buses and HGVs, EU average (2010).

Vehicle	Type	EURO-Class	Urban	Rural	Motorways	Average
			(€ct/vkm)	(€ct/vkm)	(€ct/vkm)	(€ct/vkm)
Bus		EURO-1	3.3	2.5	2.3	2.7
		EURO-2	3.3	2.4	2.2	2.7
		EURO-3	3.3	2.4	2.2	2.7
		EURO-4	3.2	2.2	2.0	2.5
		EURO-5	3.2	2.2	2.0	2.5
Truck	<7.5t	EURO-0	1.6	1.4	1.5	1.4
		EURO-I	1.3	1.2	1.3	1.2
		EURO-II	1.2	1.1	1.2	1.1
		EURO-III	1.2	1.1	1.2	1.1
		EURO-IV	1.2	1.0	1.1	1.0
		EURO-V	1.2	1.0	1.1	1.0
	7.5-16t	EURO-0	2.8	2.3	2.2	2.4
		EURO-I	2.5	2.0	1.9	2.1
		EURO-II	2.3	1.9	1.8	2.0
		EURO-III	2.4	1.9	1.8	2.0
		EURO-IV	2.3	1.7	1.6	1.9
		EURO-V	2.3	1.7	1.6	1.9

Vehicle	Type	EURO-Class	Urban	Rural	Motorways	Average
			(€ct/vkm)	(€ct/vkm)	(€ct/vkm)	(€ct/vkm)
Truck	16-32t	EURO-0	4.6	3.6	3.2	3.7
		EURO-I	4.2	3.3	2.9	3.4
		EURO-II	4.1	3.2	2.8	3.3
		EURO-III	4.2	3.1	2.7	3.3
		EURO-IV	3.9	2.8	2.4	3.0
		EURO-V	3.9	2.8	2.4	3.0
	>32t	EURO-0	5.7	4.5	3.9	4.5
		EURO-I	5.2	4.2	3.5	4.1
		EURO-II	5.1	4.0	3.4	4.0
		EURO-III	5.2	3.9	3.2	3.9
		EURO-IV	4.8	3.5	2.9	3.6
		EURO-V	4.9	3.5	2.9	3.6

Source of emission factors: TREMOVE Base Case (model version 3.3.2). Climate costs evaluated with the central value for CO2: €90/tonne. Air pollution damage costs (non-urban) from Table 15.
Note: Area definition according to TREMOVE database (de Ceuster et al., 2006, p. 124). Urban roads - roads inside urban settlement areas; motorways - non-urban motorways with separated lanes and central barrier; rural - other roads outside urban settlement areas. Definition of urban area is country-specific (more than 50000 inhabitants, in most cases).

7.1.2.2 Rail transport

For the electrically-powered trains, the starting point is the structure of the public electricity sector. The amount of emissions that can be associated with electricity use depends on the shares of different types of fuels used by the power plants. As an example, France derives roughly 75% of the total electricity supply from nuclear power plants, which are producing almost no air pollution. At the other extreme, 90% of electricity supply in Poland is produced by coal power plants. Consequently, the indirect emission factors for electrically-powered rail transport in Poland will be much higher than in France (see tables in Annex F).

In order to calculate the indirect emission factors, the following pieces of data were made use of:

- Emission factors for different fuels used at power plants in the EU, derived from the Guidebook on energy industries (EMEP/EEA, 2010b).
- Unit damage costs from Table 15
- Shares of different power plants in the electricity supply (EEA data)
- Energy use and transport volumes of freight and passenger electricity-driven trains, derived from TREMOVE v.3.2.2.

Table 43: Marginal costs of up- and downstream processes (well-to-tank emission and climate change costs) for rail transport, EU average (prices of 2010).

Type of train			Unit cost
			€/ train-km
Passenger	Electric	Locomotive	0.93
		Railcar	0.74
		High-speed train	1.30
	Diesel	Locomotive	1.58
		Railcar	1.10
Freight	Electric	Locomotive	1.81
	Diesel	Locomotive	3.19

Source of emission factors: TREMOVE Base Case (model version 3.3.2). Damage costs for air pollution (non-urban) are from Table 15 for diesel trains and from Table F-4 in the Annex for electric trains.

7.1.2.3 Air transport

Air transport results are presented in €ct/pkm and €/flight for different distance classes of aircrafts.

Table 44: Marginal costs of up- and downstream processes (well-to-tank emission and climate change costs) for air transport, EU average (prices of 2010).

Flight distance	Unit cost		Load factor
	€ct/pkm	€/flight	Passengers
<500 km	0.92	193	80
500-1,000 km	0.69	413	80
1,000-1,500 km	0.52	793	120
1,500-2,000 km	0.50	1200	140
>2,000 km	0.52	5517	220

Source of emission factors: TREMOVE Base Case (model version 3.2.2). Climate costs evaluated with the central value for CO2: €90/tonne. Air pollution damage costs (non-urban) from Table 15.

7.1.2.4 Inland Waterways

Unit cost values for up- and downstream processes for Inland Waterway vessels are differentiated by weight class and fuel technology.

Table 45: Marginal costs of up- and downstream processes (well-to-tank emission and climate change costs) in €ct/vkm for inland waterway transport, EU average (prices of 2010)

Fuel technology	Load type	Freight capacity (tonnes)						
		Motor vessels and barges				Pushed convoys		
		250-400	400-650	650-1000	1000-3000	3000-6400	6400-12000	9600-18000
Low sulphur oil	bulk, tanker	1.0	1.0	1.2	0.8	0.7	0.6	0.4
	heavy bulk	1.1	1.0	1.1	0.7	0.9	0.6	1.0
Diesel particulate filter (DPF)	bulk, tanker	1.0	1.0	1.2	0.8	0.7	0.6	0.4
	heavy bulk	1.0	1.0	1.0	0.7	0.9	0.6	1.0
Selective catalytic reduction (SCR)	bulk, tanker	0.9	0.9	1.0	0.7	0.7	0.5	0.3
	heavy bulk	0.9	0.8	0.9	0.7	0.7	0.5	0.6
DPF+SCR	bulk, tanker	0.9	0.9	1.0	0.7	0.7	0.5	0.3
	heavy bulk	0.9	0.8	0.9	0.7	0.7	0.5	0.5
Liquefied natural gas	bulk, tanker	0.8	0.8	0.9	0.6	0.6	0.4	0.3
	heavy bulk	0.8	0.8	0.8	0.6	0.6	0.5	0.5
Average load factor, tonnes	bulk, tanker	158	248	608	1356	2475	6240	9009
	heavy bulk	189	297	729	1627	2970	7020	10530

Source of emission factors: CE Delft (2011). Climate costs evaluated with the central value for CO2: €90/tonne. Air pollution damage costs (non-urban) from Table 15.

Maritime transport

Marginal costs for maritime transport are presented in the same format as for air pollution and climate change costs

Table 46: Marginal costs of up- and downstream processes (well-to-tank emission and climate change costs) in € per 1000 tkm for maritime transport (prices of 2010)

Type of ship	Average load, tonnes	European sea area				
		Baltic Sea	Black Sea	Mediterra-nean Sea	North Sea	Remaining North-East Atlantic
Crude oil tanker 0-10 kt	1761	0.9	0.9	0.9	0.9	0.9
Crude oil tanker 10-60 kt	18413	0.3	0.3	0.3	0.3	0.3
Crude oil tanker 80-120 kt	49633	0.1	0.1	0.1	0.1	0.1
Products tanker 0-5 kt	810	1.4	1.4	1.4	1.4	1.4
Products tanker 5-10 kt	3150	0.8	0.8	0.8	0.8	0.8
General Cargo 0-5 kt	1527	0.4	0.4	0.4	0.4	0.4
General Cargo 5-10 kt	4174	0.6	0.6	0.6	0.6	0.6
Bulk carrier (feeder)	1440	0.9	0.9	0.9	0.9	0.9
Bulk carrier (handysize)	14300	0.2	0.2	0.2	0.2	0.2
Bulk carrier (handymax)	24750	0.1	0.1	0.1	0.1	0.1

Source of emission factors: CE Delft (2011). Climate costs evaluated with the central value for CO2: €90/tonne. Air pollution damage costs (non-urban) from Table 15. The emissions are evaluated under the assumption that the fuel used by the vessels is produced in the EU.

7.1.2.5 Costs for infrastructure and vehicle production, maintenance and disposal

These elements of external air pollution and climate change costs are not directly related to infrastructure use. Various studies, such as INFRAS/IWW (2004a) show that the share of these costs for road transport is between 30-40% of the total external costs of up- and downstream processes. However for rail transport the share is highly dependent on the electricity generation mix (lower costs for countries with a high share of renewable electricity production mix). For air transport, costs for infrastructure and aircraft-production/maintenance/disposal represent only 2-8% of total external costs of up- and downstream processes. For inland waterways this share is between 20-30%.

8. Marginal infrastructure costs

8.1 Methodological developments and new data sources

8.1.1 Road transport

Road infrastructure costs are not included in the 2008 Handbook, but are covered by Deliverable D2 of the IMPACT study (referred to as IMPACT D2 in the rest of this chapter). The overall conclusion in IMPACT D2 was that data availability is a major problem, which did not allow reliable calculations to be made for at least half of EU-25 member states. A review of more recent literature for the current study concludes that this poor data situation prevails.

Marginal road infrastructure costs correspond to the increase in road maintenance and repair expenditures that are induced by higher traffic levels. These effects can differ by country, road type and vehicle class. Heavier vehicles tend to cause more damage to the roads, whereby the degree to which an increase in weight leads to higher damage follows a power law. Therefore, the focus of infrastructure cost studies is usually on HGVs. The results often differ across countries, which can be explained by factors such as the differing quality of the infrastructure. Roads of higher quality, which require higher initial investment expenditures, usually have longer lifetime and are less prone to damage from increased traffic.

There are two main types of studies providing unit cost estimates for infrastructure costs. The first includes econometric studies that relate the cross-section or time-series data on road infrastructure expenditures to the corresponding traffic flow data. These usually look at specific vehicle categories and road types. Second, there are national road accounts studies that provide a detailed overview of total road expenditures (capital and running costs) as well as total traffic flows, which then can be related to each other to produce e.g. average costs per vkm.

The idea of marginal costs corresponds more to the econometric approach, where the traffic elasticity of costs would capture the effect of an additional vehicle. However, as mentioned in IMPACT D2, the econometric studies often fail to deliver statistically significant results by vehicle type. In addition, even the results from different studies that analyse the effects of e.g. all HGVs as a group, cannot always be combined because of substantial discrepancies in the definition of the cost categories.

Table 47 illustrates this point. Recent studies (from Europe, USA, and Australia) providing marginal infrastructure cost estimates were analysed and classified according to the cost inventory suggested by Link et al. (1999), which was later used in the UNITE study (2002). What can be inferred from this analysis is that no two studies use the same definition of infrastructure costs. This result also provides the background for the methodology suggested and applied in IMPACT D2. The main idea is to make use of the data from the national road accounts. Under the premise that the road accounts are detailed enough, marginal costs can then be approximated by the **average variable costs**. However, this method does not provide consistent estimates. Therefore, it is first useful to clearly define the concept of variable costs.

Table 47: Infrastructure cost components included in recent studies

Classification from Link et al. (1999)				Marginal cost components included in recent studies												
Road infrastructure cost category		Part of fixed costs	Part of short-run variable costs	Source (see Box G1 in Annex G)												
				1	2*		3	4	5	6	7	8*		9	10	
Construction	Land purchase	Yes	No													
	Construction of new roads	Yes	No													
	Enlargement of roads/ adjustment to higher axle loads	Yes	No													
	Replacement investments															
	Major repairs															
	Dressing of thin layers and surfacing	Partly	Partly	x		x	x	x	x	x	x	x		x	x	x
	Repairs of bridges, supporting walls and other facilities	Partly	Partly			x	x				x	x			x	x
	Renewal															
	Replacement of layers in underground engineering	Partly	Partly	x		x	x	x	x	x	x	x		x	x	x
	Replacement of bridges and other facilities which restores the full utility value	Partly	Partly			x	x				x	x			x	x
	Construction maintenance															
	Removal of pot-holes, spilling of joints	No	Yes	x	x			x	x			x			x	x
	Minor repairs (e.g. bridge railings, noise protection walls, protection planks)	Partly	Partly		x							x			x	x
	Pavement renewal (treatment of road surface)	No	Yes	x	x			x	x			x			x	x
Ongoing mainten-ance and operation	Winter maintenance (snow sweeping)	Yes	Partly		x							x				x
	Street marking	Yes	Partly		x							x				x
	Cleaning, cutting	Yes	No		x							x				x
	Check of facility condition	Yes	Partly		x							x				x
	Servicing of bridge beddings, traffic lights for general safety reasons	Yes	No		x							x				x
Administra-tion	Overhead	Yes	No	x	x				x							
	Police/ traffic control	No	Yes		x											x
Methodology																
Econometric analysis				x	x	x	x		x		x	x		x	x	
Road accounts								x		x						x

** Marginal costs in these studies were calculated for two different cost categories*

Variable costs include certain elements of the capital costs and running costs reported in the road accounts, namely (definitions from BFS (2011)):

- *Routine maintenance and large repair measures* (part of capital costs): periodically recurring, comprehensive measures to ensure the original and the required road conditions, including in particular major repairs and activities to improve the carrying capacity of the road, to repair the drainage lines, and to strengthen the engineering structures.
- *Operational maintenance* (part of running costs): includes measures to ensure the continuous operability of the road, such as cleaning, inspection, surface treatment, winter maintenance, lighting and minor repairs to maintain the functionality.

IMPACT D2 bases its analysis on the data extracted from the UNITE case studies as well as from further road accounts for Germany, Switzerland and Austria. The UNITE case studies apply a standardised procedure to obtain infrastructure cost estimates for 17 EU countries. However, in most cases no necessary distinction could be made between cost components. Therefore, the unit values presented in the IMPACT D2 are largely based on the average cost figures for Germany stemming from Progtrans/IWW (2007). The German figures are transferred to other countries by purchasing power parity (PPP) adjustment and by using additional information about the national network length and the traffic flows. In the absence of better information, the case of Germany could be used as an average representation of the European network composition and geography. However, this is a very crude assumption, and country-specific data must be preferred if available.

8.1.2 Rail transport

The topic of rail infrastructure costs was not included in the 2008 Handbook. The calculation of these costs however has important policy implications. In the course of railway liberalisation in Europe, the network operators were obliged to reveal information about the costs that form the basis for the determination of network access charges (Directive 2001/14/EC). These charges must be based on a transparent methodology, with the direct cost of operating the railway service (plus a reasonable rate of return) forming a lower bound for such a charge.

The correct differentiation of the charge for different types of users is only possible if the marginal costs are calculated, that account for the specific contribution of different users to the total costs of infrastructure wear and tear. Most recent joint efforts in order to establish methodological recommendations for the Member States in this respect were undertaken in the course of the CATRIN project (Wheat et al., 2009). The starting point for the top-down calculations is the following representation of the marginal cost:

Marginal cost = (Average cost) x (Cost elasticity)

First, the relevant cost must be identified. Most studies concentrate on the maintenance costs only. This includes:

- permanent way costs,
- signalling and telecoms costs,
- electrification and plant costs.

More rarely, renewal costs are also considered. Network-wide overheads, however, are not relevant for determining the optimal infrastructure use charges.

The cost elasticity can consist of several components, depending on the data availability and policy needs. The components of elasticity could quantify the impact on the total cost of:

- total amount of traffic (track usage)
- type of track (electrified or not; dedicated freight or mixed line)
- type of train (passenger, freight; regional, intercity, etc.)
- speed regime

In CATRIN case studies for Great Britain, Austria, Sweden, Switzerland and France, the cost estimates are differentiated between passenger and freight and the cost elasticities are given only for three traffic density ranges (in tonne-km per annum). Cost elasticities are generally in the range of 0.1-

0.35, meaning that marginal cost-based prices will require substantial mark-ups if the full cost of maintenance and renewals is to be covered, let alone a contribution made to investment costs (Sanches-Borras et al. (2010)).

Overall, the following findings from the literature are important to note before some results are presented:

- **Impact of traffic density.** Many studies refer to the U-shaped form of the traffic elasticity, meaning that the reported econometric estimates of this elasticity decrease with density at low density values, and then increase when density reaches some threshold value (often close to the mean). According to some recent findings (Gaudry and Quinet (2013)), this effect is not always present. What remains true is that the background traffic amount is a very important factor for the level of marginal costs.
- **Ratio of passenger to freight marginal costs.** Most studies find that the marginal costs for freight trains are substantially lower than for passenger trains (1.5 to 7.5 times, according to the estimates in Wheat et al. (2009)). Gaudry and Quinet (2013) name the following reasons for this phenomenon: repairs on passenger-only lines must happen much faster and are thus more expensive; segments with a large proportion of freight trains do not require a high level of quality; due to shortage of funds, freight lines are more likely to get cheaper preventative maintenance rather than more expensive curative maintenance.
- **Type of econometric model.** Modern econometric techniques allow the use of estimating models with nonlinear parameters. This may lead to a revision of older estimates using exclusively linear models.
- **Power function for load damage.** For road transport, the fourth-power law (see next section for an explanation) is applied to allocate damage costs to vehicles with different axle load. In rail transport, the dominant view is that the relation is simply linear. Gaudry and Quinet (2013) present some indication that non-linear relationships with the power factor greater than unity may be plausible, but there is no strict proof of this so far.

Railway infrastructure maintenance cost functions have been, in the last decade, estimated in Austria (Munduch et al., 2002), Finland (Johansson and Nilsson 2004, Tervonen and Pekkarinen, 2007), Switzerland (Marti and Neuenschwander, 2006), Sweden (Johansson and Nilsson, 2004; Andersson, 2011) and the UK (Wheat and Smith, 2008). The following table reports recent estimates, which have all been adjusted to be expressed in 2010 prices.

Table 48: Summary of recent estimates for marginal rail maintenance costs

Study	Country	Traffic type	Marginal cost, € per 1000 tkm
CATRIN D8: Wheat, P. et al. (2009)	Sweden	passenger	1.33
		freight	0.17
		all traffic	0.57
CATRIN D8 - Annex 1B: Marti. et al. (2009)	Switzerland	passenger	0.29
		freight	0.20
		all traffic	0.35
CATRIN D8: Wheat, P. et al. (2009)	France	passenger	2.28
		freight	0.75
		all traffic	1.51
CATRIN D8 - Annex 1F: Wheat, P., Smith, A. (2009)	Europe (pooled)	all traffic	2.35
Andersson, M. (2011)	Sweden	passenger	1.41
		freight	0.18
		dedicated freight lines	2.20
Wheat and Smith (2008) (6 different model settings)	Great Britain	all traffic	1.54-1.92
		passenger	1.05-1.32

Study	Country	Traffic type	Marginal cost, € per 1000 tkm
		freight	1.32-1.72
Johansson and Nilsson (2004)	Sweden	all traffic	0.16
		main/electrified	0.11
		secondary/non-electrified	1.20
	Finland	all traffic	0.29
		main/electrified	0.22
		secondary/non-electrified	0.49
Tervonen and Pekkarinen (2007)	Finland	all traffic	0.33
Munduch et al. (2002)	Austria	all traffic	0.71
Gaudry and Quinet (2013)	France	all traffic	1.39
		intercity passenger	1.72
		regional passenger	4.58
		freight	0.69

It can be noticed that more recent estimates are substantially higher than the earlier results (before 2006) cited in the CATRIN or GRACE deliverables. Wheat and Smith (2008) stress that their high estimates may be explained by the special case of Great Britain. In the light of other recent results, however, one can see that the current marginal costs may well be above €0.50 per 1000 tkm on average for all traffic, and above €1 per 1000 tkm for passenger traffic.

UIC (2010) is one of the few studies that explicitly looks at the effects of train speed on marginal infrastructure costs. The results, however, suggest that this factor is of limited importance. For high-speed trains, the increase of speed from 100 to 300 km/h leads to an increase in marginal cost of only 11%. For commuter trains, the effect is negligible.

8.2 Updated unit values for infrastructure costs

8.2.1 Road transport

For calculating the illustrative unit values, the approach used here is similar to the approach in IMPACT D2, i.e. the estimates are based on the available detailed road accounts. Table 49 provides unit values for Germany based on the most recent evaluation by Link et al. (2009). This evaluation is the most detailed in terms of differentiation of vehicle types and road types. It reflects the structure of the traffic flow and variable cost composition in Germany as of year 2007.

Table 49: Average variable infrastructure costs for Germany, eurocent/vkm, 2010 prices

Vehicle type	All roads	Motorways	Other trunk roads	Other roads
Mopeds and motorcycles	0.2	0.1	0.2	0.3
Passenger cars	0.6	0.3	0.3	0.9
Buses	2.2	0.9	1.5	2.9
LDV	0.8	0.3	0.5	1.3
HGV 3.5-12 tonnes	1.3	0.6	0.8	2.9
HGV 12-18 tonnes	4.1	1.9	2.7	20.8
HGV >18 tonnes	6.6	2.8	4.6	37.7
Average	0.9	0.6	0.5	1.4

Source: Own calculations based on Link et al. (2009). Road types are as described by the parameters in Table 50 below.

An important further step is the differentiation of the unit values for subcategories of the high-weight trucks, which are responsible for the major part of road damage costs. To this end, data in Table 49 was used to calculate the infrastructure cost per equivalent standard axle load (ESAL), corresponding to axle load of 10 tonnes. This was done in several steps.

For each HGV category of interest, the number of ESALs (*N*) was calculated according to the "fourth power law"[16]:

$$N = \sum_i \left(\frac{L_i}{L_0}\right)^4,$$

where *i* is the number of axles, L_i is the axle load at every axle in tonnes, and L_0 = 10 tonnes. The details of these calculations are explained in Annex G.

Further, the traffic flow data from Link et al. (2009) was weighted with the respective average ESAL factors for the LDV and HGV subgroups (groups defined in Table 49). The average variable costs from Table 49 were then divided by the ESAL-weighted vehicle.

This delivered the following estimates of marginal infrastructure costs per ESAL-km of HGVs in Germany: 2.8 €ct for motorways, 4.6 €ct for other trunk roads, and 36.7 €ct for other roads, with an average for all roads equal to 6.6 €ct per ESAL-km (prices of 2010).

By combining the estimates of costs per ESAL and the ESAL factors of vehicles, infrastructure costs for different HGV categories can be calculated.

Before transferring these values to other EU Member States, two aspects have to be stressed. First is the type of road under consideration. The three types of roads in the German methodology (Table 49) can be characterised with the help of two indicators: the average axle number factor (average number of axles per freight traffic vehicle) and the load spectrum quotient (ratio of the sum of the number of equivalent standard axles (ESAL) and the sum of the number of actual axles for all vehicles on the road). These indicators for the German roads are listed in Table 50. Blanc-Brude et al. (2006) further suggest that number of lanes, urban terrain, and presence of bridges and tunnels are important cost drivers. These factors should be taken into account when doing a more locally specific impact assessment.

Table 50: Technical characteristics of roads in German road accounts

Road class	Class definition	Axle number factor	Load spectrum quotient
Motorways	Federal motorways or municipal roads with freight traffic share > 6%	4.5	0.33
Other trunk roads	Federal roads or municipal roads with freight traffic share > 3 % and ≤ 6 %	4.0	0.25
Other roads	Municipal and district roads or municipal roads with freight traffic share ≤ 3 %	3.3	0.23

Source: Guidelines for the Standardisation of Surfaces of Road Traffic Areas, 2012 Edition (RStO 12).

The second aspect is the difference in construction costs across countries. The evidence presented in IAE/Forfas (2011) suggests that differences in the road construction costs are to a large extent explained by the differences in civil engineering price indices.

For the purpose of producing the illustrative country-specific unit costs in this study, only this second aspect of the influence of price variation on average construction costs could be taken account of. The aforementioned technical characteristics of the roads are therefore assumed to be the same in all countries, which is a very strong assumption.

[16] Fourth power law is known to reflect well the damage for the road surface. For bridges and tunnels, a lower power law may be more appropriate,

Table 51 reports the resulting unit values. The values are for EU average, with an adjustment of average variable cost values of Table 49 carried out with the help of the price indices for civil engineering works (source: Eurostat).

Table 51: Illustrative marginal infrastructure costs for EU*, €ct (2010) per vkm

Vehicle category	All roads	Motorways	Other trunk roads	Other roads
Motorcycles and mopeds	0.2	0.1	0.1	0.3
Cars	0.5	0.2	0.3	0.8
Buses	2.0	0.8	1.4	2.7
LDV < 3.5 t	0.7	0.3	0.5	1.2
HGV 3.5 - 7.5 t, 2 axles	0.1	0.0	0.0	0.4
HGV 7.5 - 12 t, 2 axles	1.5	0.6	1.0	8.2
HGV 12 - 18 t, 2 axles	3.9	1.6	2.7	21.5
HGV 18 - 26 t, 3 axles	5.2	2.2	3.6	28.9
HGV 26 - 32 t, 4 axles	6.6	2.8	4.6	36.7
HGV 26 - 32 t, 5 axles	3.6	1.5	2.5	20.1
HGV 32 - 40 t, 5 axles	8.0	3.3	5.6	44.6
HGV 32 - 40 t, 6 axles	4.8	2.0	3.3	26.7
HGV 40 - 50 t, 8 axles	5.0	2.1	3.5	28.1
HGV 40 - 50 t, 9 axles	3.8	1.6	2.7	21.5
HGV 50 - 60 t, 8 axles	10.6	4.4	7.4	59.3
HGV 50 - 60 t, 9 axles	7.6	3.2	5.3	42.3
HGV 40 t, 8 axles	3.5	1.5	2.4	19.4
HGV 40 t, 9 axles	2.8	1.2	2.0	15.6
HGV 44 t, 5 axles	18.8	7.9	13.1	105.0
HGV 44 t, 6 axles	10.3	4.3	7.2	57.7

Source: Own calculations based on Link et al. (2009). Road types are as described by the parameters in Table 50.
** Country-specific values are provided in Excel tables as Annexes to this report*.

As expected, the results show a very sharp progression of average variable (marginal) costs with vehicle weight. For the heaviest vehicles the number of axles on which the load is distributed also plays a crucial role, due to the “fourth power law”. In order to produce plausible country-specific unit costs, detailed road accounts for the country in question are needed, which would allow to take the local structure of traffic into account. In their absence, a value transfer as made for Table 51 can serve as a first approximation. In Annex G, we present marginal cost estimates for HGVs from CE Delft (2010) for France, Belgium, and the Netherlands. The marginal cost values are similar across countries and very close to our estimates in Table 51.

8.2.2 Rail transport

The range of values listed in Table 48 may provide an indication of the marginal infrastructure costs for rail transport. However, the unit of measurement used in most studies is not very useful for policy purposes, where a calculation in terms of train-km would be preferred. Thompson (2008) suggests using a typical value of 960 gross tonnes for the freight train, 590 gross tonnes for an intercity passenger train and 270 gross tonnes for a suburban passenger train. This would imply a range €0.7 to €1.3 per train-km for passenger trains, and €0.2 to €0.7 per train-km for freight trains. However, the available literature does not allow deriving direct recommendations from these values.

A key finding of CATRIN (Wheat et al. 2009) research on rail cost allocation is that even when evaluated at country-specific mean values for the traffic flow, marginal costs vary considerably between countries and within countries as well. These differences are driven by many factors such as infrastructure quality and traffic density. Thus it is difficult to generalise the results on marginal costs. Therefore, the recommendations are limited to the conclusions of Wheat et al. (2009).

Wheat et al. (2009) advocate using estimates of usage elasticities rather than specific marginal costs. Usage elasticity shows by what percentage the infrastructure costs will increase if traffic increases by 1%. These can then be multiplied by country specific average cost estimates (this information may not be publicly available) to yield estimates of marginal cost. The authors do still find some variation in usage elasticities within countries, but there is a more systematic pattern which allows making recommendations for usage elasticities based on traffic density of the network.

Table 52: Recommended elasticity for rail maintenance costs

Traffic density range, train-km per annum	Low <3 mln train-km	Medium <10 mln train-km	High >10 mln train-km
Recommended usage elasticity of rail maintenance cost	0.2	0.3	0.4

Source: Wheat et al. (2009), p. 62.

Wheat et al. (2009) demonstrate that marginal costs differ considerably by traffic density and infrastructure quality. This supports setting differentiated charges for routes characterised by different traffic density and infrastructure quality. This will be more cost reflective although there is the obvious trade-off between cost reflectiveness and complexity. The approach of Wheat et al. (2009) allows for this flexibility. The differentiation can be undertaken by the country simply providing average cost by route, choosing a suitable elasticity for each route from the research and applying the relationship Marginal cost = (Average cost) x (Cost elasticity).

8.2.3 Inland waterway transport

CE Delft et al. (2010) provide infrastructure cost figures for inland waterways in the study of the Paris-Amsterdam corridor gathered from a few relevant studies. We adapt the information from this review below.

France

The infrastructure costs of inland navigation in France are estimated based on recent studies of Alenium for the French waterway operator VNF (VNF, 2009).

Fixed costs have been defined for each of the three activities of VNF (navigation, water management and public property management). However, it is clear that water management and public property are not relevant in the context of transport infrastructure external costs and for this reason, only the fixed costs of VNF with regard to navigation (maintenance of canal banks, bridges, beacons, radars, dredging costs, etc.) were allocated to inland waterway transport by CE Delft et al. (2010). Variable costs data only apply to the navigation function.

To calculate the average infrastructure costs, these figures are divided by the traffic volume in France in 2007 calculated from data provided by VNF. A distinction is made between infrastructure costs of large channels (‘Grand Gabarit’) and small channels (‘Petit Gabarit’). The results are shown in Table 53.

Table 53: Infrastructure costs of inland navigation in France (price-level 2010)

	Large channels (Grand gabarit)			Small channels (Petit gabarit)		
	Fixed	Variable	Total	Fixed	Variable	Total
Total costs (min. €)	80	35	115	113	71	185
Average costs (€ct/tkm)	1.39	0.61	1.99	6.38	4.01	10.39

Source: CE Delft (2010).

The Netherlands

The infrastructure costs of inland navigation in the Netherlands are estimated based on CE Delft (2004). In CE Delft (2004), total infrastructure costs of inland navigation are estimated using the permanent inventory approach. Construction costs are depreciated over a period of 35 years by using an interest rate of 4%. The land use costs are depreciated over an infinite time period also using an interest rate of 4%. Finally, the maintenance and operational costs are based on running expenditures.

The total infrastructure costs are allocated to passenger (recreation) and freight inland shipping. The most important cost driver is the number of vehicle-kilometres.

Results for 2002 are shown in Table 54. To calculate the average infrastructure costs these figures are divided by the total number of inland navigation in the Netherlands in 2002. Marginal infrastructure costs are equal to the average variable costs.

Table 54: Infrastructure costs of inland navigation in the Netherlands (price level 2010)

	Fixed	Variable	Total
Total costs (mln. €)	654	33	687
Average Costs (€ct/tkm)	1.50	0.08	1.58

Source: CE Delft (2010).

Belgium

In Belgium, operational and management costs of inland waterways are equal to ca. € 230 million (Waterwegen en Zeekanaal NV, 2010). About 60% of these costs can be allocated to inland waterway transport, i.e. € 138 million. CE Delft et al. (2010) assume that, like in the Netherlands, ca. 9% of these costs are variable and 91% are fixed.

No estimates of construction costs of inland waterways in Belgium are available. CE Delft et al. (2010) were also not able to estimate these costs themselves, since no time series on investments in inland waterways in Belgium are available. Therefore they assumed that construction costs per tonne-kilometre in Belgium are the same as in the Netherlands. Average infrastructure costs of inland navigation in Belgium are presented in Table 55.

Table 55: Infrastructure costs of inland navigation in Belgium (price level 2010)

	Fixed	Variable	Total
Average Costs (€ct/tkm)	2.05	0.14	2.19

Source: CE Delft (2010).

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Annex A. Congestion costs

A1. Road congestion costs

A1-1. The conventional deterministic model of traffic flow

The conventional congestion model for flows along links starts from the characteristic of a link as described by the so-called fundamental diagram. The diagram relates speed along a link to the flow. Alternatively, transformations of these variables are related to each other in a way encompassing the same information. Much effort in the literature over the last decades has gone into specifying functional forms of the diagram and estimating its parameters. For a review and unifying framework see Li (2008). It will be shown that these efforts have little bearing for quantifying the EMCC in practice. Estimates are not much affected by choosing among these forms. Uncertainties and ambiguities lie elsewhere.

Figure A-1 shows four different ways to depict the fundamental diagram. The variables on the axes are ([veh] denotes the number of vehicles)

- speed v [km/h]
- flow f [veh/h],
- density d [veh/km],
- headway h (i.e. centre-to-centre distance between cars) [km/veh], and
- travel time t [h/km].

These variables are related according to $d = 1/h$, $t = 1/v$, and $f = vd$. The functional form chosen for the curves in the figure is what Li (2008) calls the Newell-Franklin speed-flow relationship. This curve is extended by combining it with a linear segment at the lower-left end in the headway-speed diagram. As different forms seem to perform equally well in reproducing the data, and as the forms do not matter much anyway, this form has been chosen for convenience. It is convenient because it is characterised by just four easily observable parameters, the maximal speed v_{max}, the maximal flow (also called capacity) $\bar{f}$, the critical speed (i.e. the speed at which the maximal flow is attained) v^*, and the minimal headway (the headway at speed zero) h_{min}.

Figure A-1: The Fundamental Diagram of traffic flow. Newell-Franklin function for one lane, maximal speed 120 [km/h], maximal flow 2100 [veh/h] at critical speed 90 [km/h].

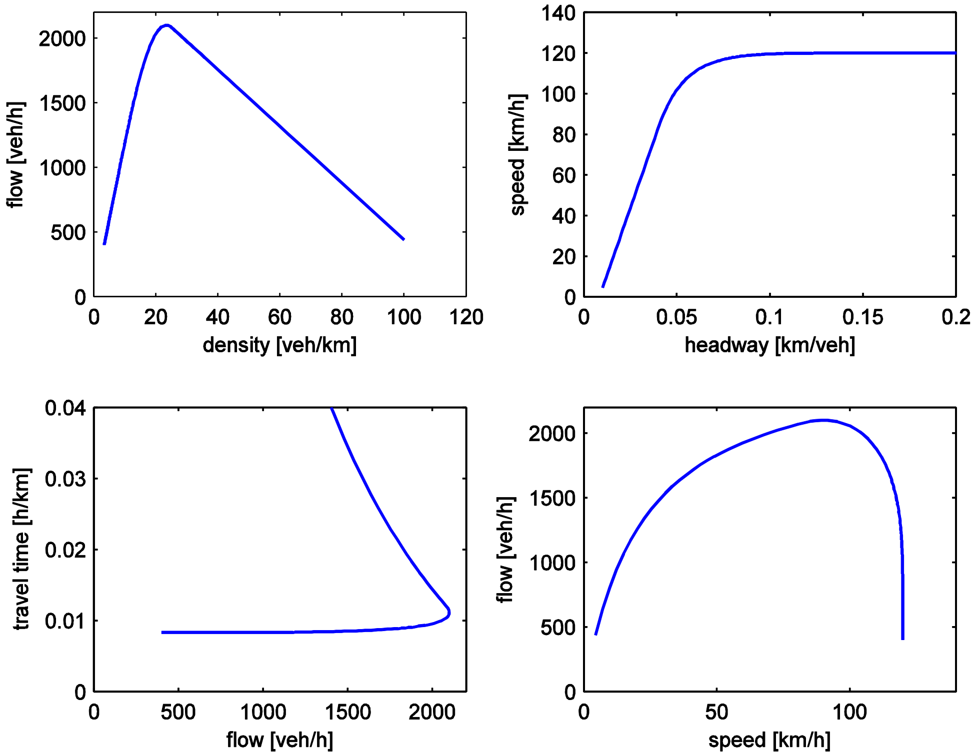
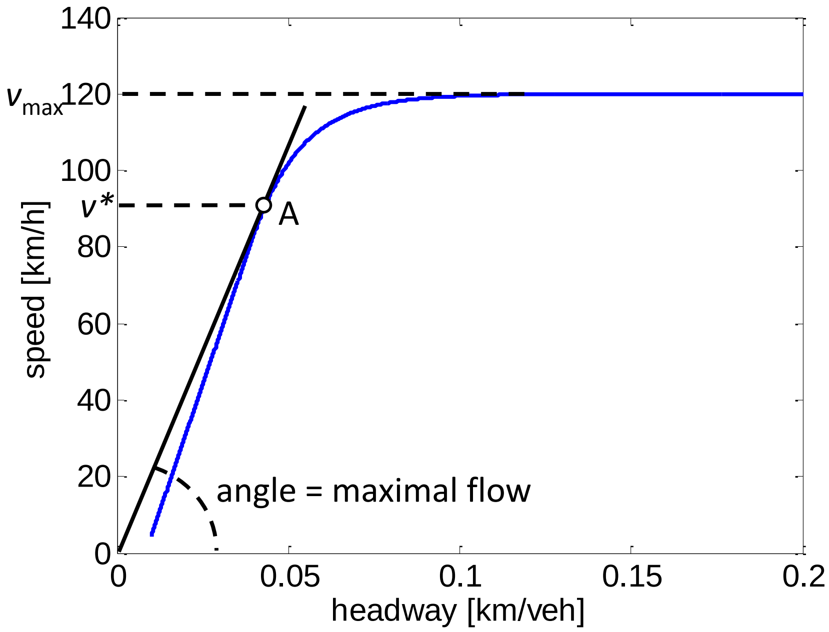


Figure A-2: Headway-speed diagram. Newell-Franklin function for one lane, maximal speed [120 km/h], maximal flow 2100 [veh/h] at critical speed 90 [km/h].

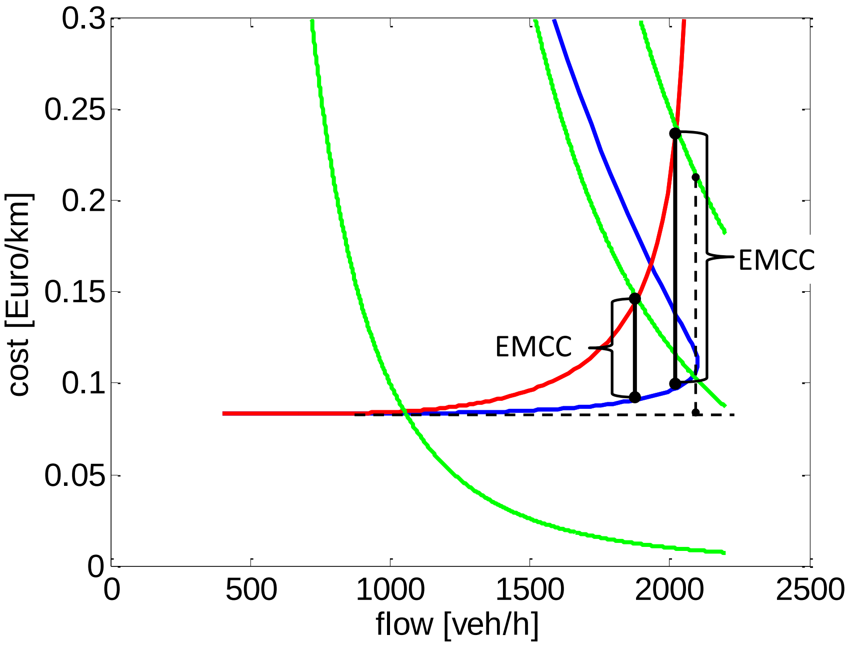


In the conventional model that is considered first, the domain of hypercongestion is irrelevant, because an optimal road price will always keep the headway above the critical value $h*$ and thus the speed above the critical value $v*$. It will be shown however later that hypercongestion does occur and does matter for determining an optimal road price. This is why one has to go beyond the conventional model. The congestion externality is shown in Figure A-3. The blue curve in Figure A-3 is the same as in the flow-travel time diagram, with the only difference that the value on the ordinate is multiplied by the average value of time φ . For convenience, it is assumed to be 10 [Euro/h] in Figure A-3. Values on the ordinate thus show the time cost in Euro per kilometre. The congestion externality is the slope of this curve multiplied by the flow, measured also in Euro per kilometre. The red line shows the time cost plus the externality. This is the social marginal cost curve, neglecting any out-of-pocket costs that do not depend on flows. In formal terms the congestion externality is

$$\begin{aligned} E &= \varphi f \frac{\mathrm{d}\, t(f)}{\mathrm{d} f} \\ &= \varphi\, \varepsilon(t:f)/v \\ &= -\frac{1}{\varepsilon(f:v)} \frac{\varphi}{v} \\ &= \frac{\varepsilon(v:h)}{1-\varepsilon(v:h)} \frac{\varphi}{v}. \end{aligned} \qquad (2)$$

$\varepsilon(y:x)$ denotes the elasticity of y with respect to x, i.e. the percentage change of y per one per cent increase of x.

Figure A-3: Efficient marginal congestion cost (EMCC) for low, medium and high demand. The cost is 10 [Euro/h] divided through speed, taken from Figure A-2. Demand elasticity is -0.3.

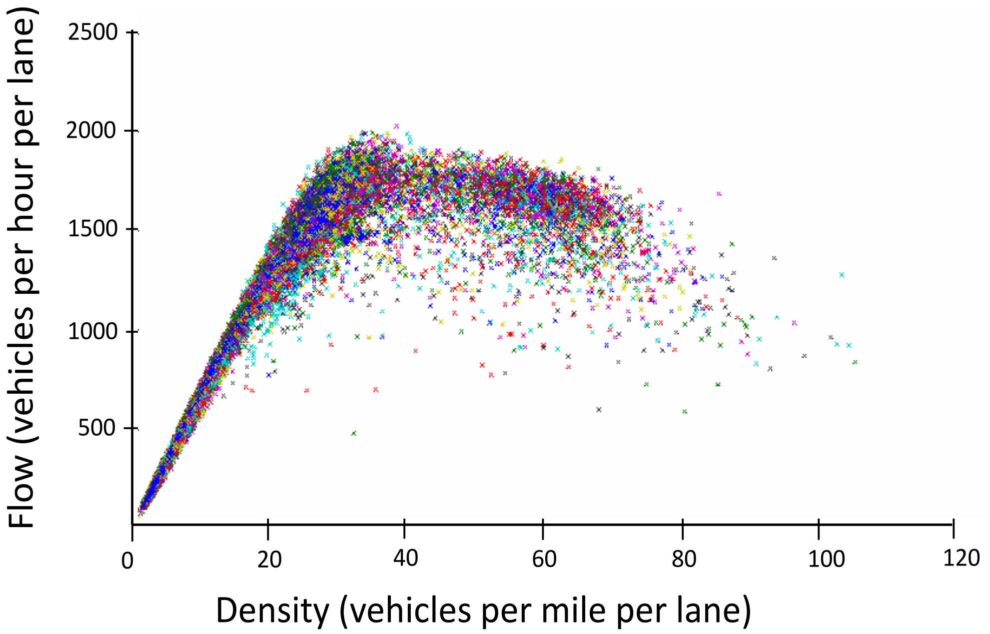


Given this specification of the fundamental diagram, the externality is virtually zero over a wide range of flows (up until more than 1000 vehicles per hour), and then, as the flow approaches the capacity, it starts to rise sharply. It tends to infinity as the flow tends to capacity.

To determine the EMCC on a certain link one need to know, in addition to the fundamental diagram, also the position of the demand function. Figure A-3 includes three demand functions representing low, medium and high demand in the figure. The respective EMCCs are the vertical differences between the red and the blue curve. It is obvious from the figure that, except for a small range of medium demand curves, the EMCC is either close to zero or almost equal to the difference between the willingness to pay for the flow capacity (the point where demand cuts a vertical line at $\bar{f}$) and the cost at free flow. For the high demand case this approximate EMCC is displayed by the length of the vertical dashed line in the figure. Knowledge of the actual flow does not help much in determining the EMCC. One needs to know the position of the demand curve.

The overall conclusion is that a useful ad-hoc rule for an EMCC just based on observations of flows or speeds does not exist in the conventional model. The essential information needed, namely the position of the demand curve, is not observable on the road link. It has to be obtained from a network assignment model. There is little chance to arrive at any sensible number on the EMCC along a road without calibrating such a model. This is also true because road links in a network interact; what is required to determine the EMCC is not the position of the demand curve under conditions of a decentralised inefficient equilibrium, but under the condition that on all links users are charged in an efficient way.

Figure A-4: Scatter plot of density-flow diagram, taken from Dervisoglu et al. (2009)



A1-2. Congestion charging in a stochastic model of traffic flow

One has to go beyond the conventional model, because it is based on a deterministic approach to the relation between speed and flow, while modern traffic flow theory favours a stochastic approach (Treiber und Helbing 1999; Treiber, Kesting, and Helbing 2010; Kerner 2009). This approach emphasises phase transitions between free-flow conditions where cars move along the road with almost full speed, and queues emerging stochastically. This shows up in a scattered density-flow diagram, as in Figure A-4. Such a diagram has a linear left branch representing varying densities at a speed almost unaffected by densities, and scattered points representing hypercongested traffic. Though there is no unanimity, neither in naming the phase of non-smooth flow nor even regarding the number of phases to be distinguished, a distinction between free flow and hypercongestion is sufficient for expositional purposes at this point. For a given position of the demand curve a free flow or a congested traffic situation may prevail, with certain respective probabilities. While the conventional approach assumes that speed continuously declines with increasing density, the stochastic approach suggests an increasing instability, with an increasing probability of traffic getting stuck if the density goes up.

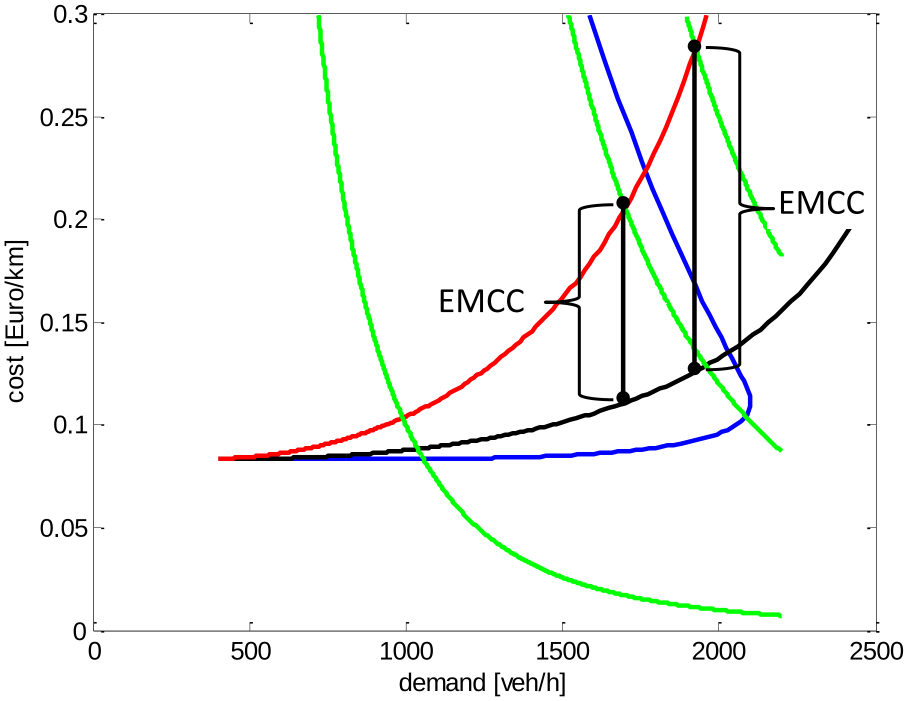
In a situation described by this framework a user does not care about the actual cost of travelling, which is unpredictable, but about the expected disutility. The appropriate concept to translate it into a monetary amount is the certainty equivalent. For defining it one has to introduce the flow demand F [veh/h] replacing the actual flow f. It represents the number of vehicles per hour whose drivers would like to pass the link given the traffic conditions on the link. These conditions are not characterised by a certain travel time, but by a distribution of travel times t. The probability density function is denoted $\tau(t,F)$. The certainty equivalent of the travel cost, $C(F)$, briefly called the cost expectation in the following (again neglecting out-of-pocket cost that do not depend on flows), is implicitly defined by

$$u\left(W - C(F)\right) = \int_0^\infty u(W - \varphi t)\tau(t,F)\,\mathrm{d}t\,,$$

where u denotes the decision maker's utility and W denotes her initial wealth. One typically assumes constant absolute risk aversion implying $C(F)$ to be independent of W. An alternative approach would define a cost expectation applying prospect theory, which may lead to a more realistic description of a driver's decision making (Gao, Frejinger and Ben-Akiva 2010).

For a risk-neutral user u is affine, such that $C(F)$ is just the expected cost. But for a risk-averse user, which is the realistic case, the cost expectation is larger than the expected cost, because the user would be willing to pay a risk premium on top of the expected cost if she could get rid of the uncertainty.

Figure A-5: Efficient marginal congestion cost (EMCC) for low, medium and high demand, based on stochastic travel times. The cost expectation (black curve) is drawn arbitrarily, not based on empirical observation. The deterministic cost curve is from Figure A-3.



The decentralised user equilibrium is now the point where the cost expectation function and the demand function cut, as shown in Figure A-5. Note the difference between the function $C(F)$ and the cost function in Figure A-2. On the one hand, for F less than the capacity $\bar{f}$, $C(F)$ is strictly above the cost function, because the system switches to the hypercongestion phase with a certain positive probability. On the other hand F can be larger than $\bar{f}$, because cars can queue up. More than $\bar{f}$ of them enter the link and get through after a sufficiently long waiting time.

The externality is defined as in Equation (2), with demand F replacing the flow f and the cost expectation $C(F)$ replacing $\varphi t(f)$,

$$E = F \frac{\mathrm{d}\, C(F)}{\mathrm{d}\, F}.$$

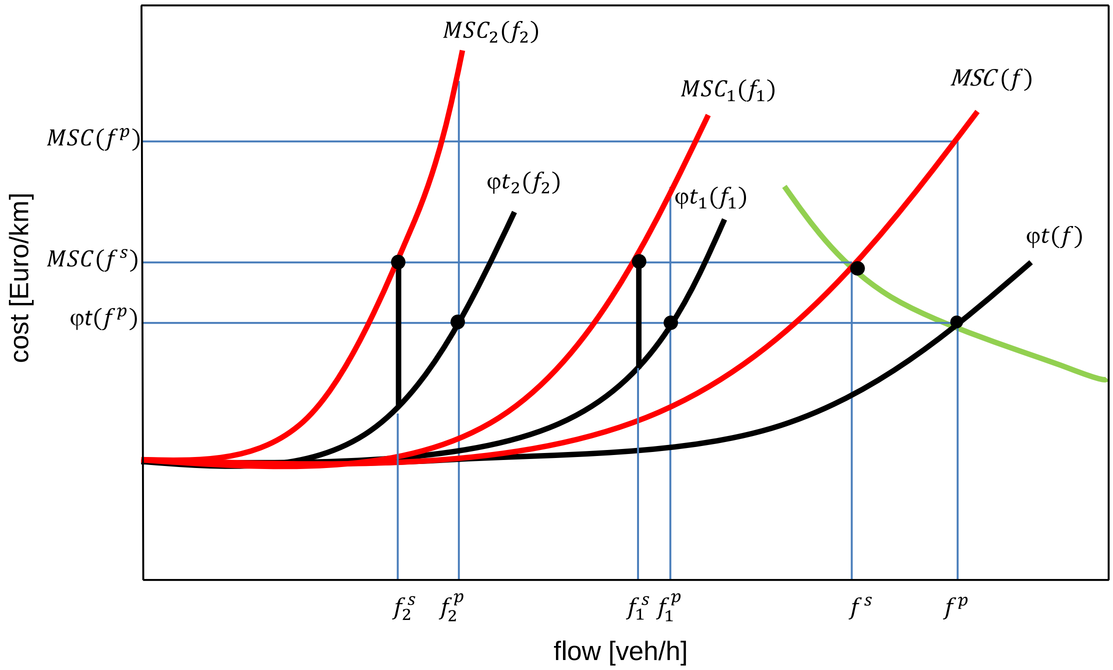
Unfortunately, while there is extensive literature on the best fitting speed-flow relations for the deterministic approach, there is no useful literature yet allowing for a calibration of the function $C(F)$. It is recommended to put more effort into estimating it, using stochastic flow models of the last generation.

A1-3. Review of existing software tools

In computational terms, finding the user equilibrium and the system optimum are related problems. While the user equilibrium according to Wardrop's first principle is constituted for each OD-pair by a set of link flows such that all links i with positive flows f_i involve the same travel cost $\varphi t(f_i)$[17], the system optimum according to Wardrop's second principle is constituted equivalently, except that all links i with positive flows involve the same marginal social cost $MSC(f_i)$. In fact, the system optimum is the user equilibrium for the cost function $MSC_i(f_i) = \varphi t_i(f_i) + \varphi f_i \frac{dt_i(f_i)}{df_i}$.

Figure A-6 illustrates this simplistically for one OD-pair which is connected by two links $i = \{1, 2\}$ such that $f_1 + f_2 = f$. The flows constituting the user equilibrium are indexed by p and those constituting the system optimum are indexed by s. The social suboptimality of the user equilibrium can be split up into two aspects: Given the user equilibrium flow f^p for an OD-pair, the travelers do not assign themselves socially optimally to the links connecting that OD-pair, that means the $MSC_i(f_i^p)$ differ. Second, for a given OD-pair the flow f^p itself is too large. Given a flow-dependent demand function for each OD-pair, which is illustrated as the green line in the figure, and the fact that $f_1^s + f_2^s = f^s$, the socially optimal OD-flow f^s can be accomplished by internalizing the respective efficient marginal congestion costs (EMCC) at each link depicted by the two black vertical lines in the figure.

Figure A-6: Efficient marginal congestion costs in the case of two links connecting one OD-pair.



As shown above, in the proposed stochastic model the cost function $\varphi t(f)$ relating traffic flow to travel cost is replaced with the cost expectation function $C(F)$, with flow demand F [veh/h]. For a risk-neutral user, the cost expectation $C(F)$ is just the expected travel cost, which is the expected value of the uncertain travel times which might occur for a demanded flow F, with each travel time being weighted by the probability of its occurrence. Observations show that a specific flow can prevail under free flow or under hypercongestion. It would be straightforward to distinguish between these two scenarios and to assign flow-dependent probabilities to the corresponding travel times. Availability of an empirical estimate of such a link-specific cost expectation function $C(F)$ would make existing computational tools applicable to the proposed stochastic model of traffic flow.

The applicability of the proposed software packages depends on to which extent the models enable the user to apply self-defined cost functions. The two packages Emme and Visum provide several types of cost functions and the corresponding marginal social cost functions. This makes both models capable of calculating the system optimum of a network traffic assignment. In this respect, SATURN is restricted by the fact that the power function is the only functional type that is applicable. The possibility to apply cost expectation functions $C(F)$ as user-defined cost functions makes Emme and

[17] Throughout, we only deal with time costs. In applications, out-of-pocket cost must be added to the time costs of links or paths.

Visum suitable for the stochastic model of traffic flow described in Section A1-2. Again, SATURN is restricted by the fact that the power function is the only functional type that is applicable.

Emme

Emme is a transportation simulation software, which has been developed by the Canadian company INRO. The most current version Emme/4 was launched 2013. A 30-days trial version is available at http://www.inrosoftware.com/en/products/emme/index.php.

Basic features of Emme:

http://www.inrosoftware.com/en/products/emme/standard_toolbox.php

It is a static deterministic assignment model and is macroscopic in the sense that it is an OD matrix trip-based application. The software has its use primarily in evaluating transport policies, and further is capable of calculating the system optimum of a network traffic assignment.

Due to Emme's flexible and open approach to modelling, it is possible to replace the private cost functions $\varphi t(f)$ with the marginal social cost functions $MSC(f)$ that take the marginal costs of all other users into account. Both the user equilibrium and the system optimum can be calculated by the fixed demand auto assignment model which minimises the sum of the areas under the respective cost functions, subject to constraints as explained on page 6-7 in the Emme/2 user's manual. This makes the implemented Frank-Wolfe linear approximation algorithm applicable to both of them. The variable demand auto assignment model implemented in Emme computes both the link flows and the OD demands (see Emme/2 User's Manual, page 6-17). The model minimises under constraints the difference between the total travel costs on all links and the total willingness to pay for all OD-pairs.

Visum

Visum is a macroscopic transportation simulation software, which has been developed by the German company PTV. The current Version 12.5 was launched 2012. A 30-days trial version is available at http://vision-traffic.ptvgroup.com/en-us/products/ptv-visum/.

Basic features of Visum:

http://vision-traffic.ptvgroup.com/en-us/products/ptv-visum/functions/

The package is comparable to Emme. On the one side, it has its use in the prognosis of the impacts of given road tolls on travellers. The traveller's criterion for choosing a path p is to minimise $\sum_{L\in p} t(f_L) + \sum_{L\in p} c_L / \varphi$. c_L may be the toll value for using link L, which is assumed to be invariant of link flow f_L. Since c_L is not flow-dependent, it is a given model input. The toll for driving from A to C via B may not be equal to the sum of A to B and B to C. These nonlinear toll schemes can be modelled within Visum as a price matrix between link entries and exits. The extension package TRIBUT contains a bicriterion equilibrium assignment method which considers travel time and cost. The trip choice between different paths is modelled by defining the value of time as a random variable, thus considering that each trip has a specific willingness to pay a toll for a travel time reduction. See Visum 12.5 user manual (2012), page 1007, Visum 12.5 fundamentals (2012), page 370.

On the other side, equivalent to Emme, Visum is capable of calculating the system optimum of a network traffic assignment. Visum provides various types of strictly increasing cost functions (BPR functions, conical functions and others), which are called as volume-delay-functions. The provided marginal-cost version of the conical function, proposed by Spiess (1990), allows the user to calculate a system optimum instead of a user equilibrium. Like Emme, Visum allows to apply user-defined cost functions. "Generally any programming language can be used, as long it can produce a Windows *.dll file which exposes an interface equivalent to the C++ function declarations. The functions need to be continuous and strictly increasing with respect to traffic flows." See Visum 12.5 user manual (2012), pages 945-963, and Visum 12.5 fundamentals (2012), pages 210-300.

Visum provides several assignment procedures, which comprise static assignment procedures as well as procedures which use a time dynamic traffic flow model. In terms of static assignment procedures Visum offers inter alia equilibrium assignment and stochastic assignment procedures. Further, dynamic stochastic assignment is implemented as well. See Visum 12.5 user manual (2012), pages 979-1027, or Visum 12.5 fundamentals (2012), pages 301-417.

SATURN

SATURN (Simulation and Assignment of Traffic in Urban Road Networks) is a software package for the analysis of traffic on road networks. It has been developed by the Institute for Transport Studies (ITS) at the University of Leeds (http://www.its.leeds.ac.uk) and is being distributed by Atkins Ltd. (http://www.atkinsglobal.com). The latest version is 11.2.05 and was published in April 2013.

Home page: http://www.saturnsoftware.co.uk
Manual: http://www.saturnsoftware.co.uk/saturnmanual

Basic features of SATURN	
Inputs	- Trip matrix - Network specifications - Link-specific time-flow curves (optional) - Link-specific tolls (optional)
Time-flow curves	- Linear/exponential function starting at free-flow travel time - Constant travel time for flows above capacity
Tolls	- Additive - Distance-based/cordon-based
Outputs	- Link-specific flows - Cost matrix

The software can be used for the static assignment of traffic in potentially very large (regional or even national) road networks and for the static/quasi-dynamic simulation and/or assignment of traffic at everything from individual junctions to localised networks. In both cases it allows for the analysis of a wide range of road-investment schemes and traffic management measures. Besides, it includes a trip matrix demand model for trip distribution and modal split. The available assignment types include the Wardrop Equilibrium (e.g. using the Frank-Wolfe Algorithm) as well as the Stochastic User Equilibrium (SUE), among others.

The inputs to the assignment model that generally need to be provided by the user are the trip matrix and the network specifications. The latter are usually such that congestion arises at the nodes while links have a (quasi-)infinite capacity. That means that the speed on a link always is at its free-flow level, even if the flow is at the upstream node's capacity. However, it is possible to assign time-flow relationships to the links. These then must have the functional form that travel time t as a function of traffic flow f is given by $t(f) = t_0 + Af^n$ for $f \leq \bar{f}$ with $t(\bar{f}) = \bar{t}$ and $t = \bar{t}$ for $f > \bar{f}$. The free-flow travel time t_0, the travel time at capacity $\bar{t}$, the capacity $\bar{f}$, and the power n are required as inputs by the user. The parameter A is calibrated such that $t(\bar{f}) = \bar{t}$.[18]

Deterministic model

Due to that restriction on the form of the time-flow curves, one should be cautious when using SATURN to determine the social optimum by simply supplying it with the links' marginal social cost curves instead of the average private cost curves (time-flow curves) as described earlier in this section. It is recommended to assign to $\bar{f}$ a large value well above any values that could be expected as flows, and $\bar{t}$ accordingly. That is to ensure that the relevant parts of these curves do not include any horizontal segments. Since the costs received as output in that case only give the marginal *social* costs, the corresponding flows need to be used to manually calculate the marginal *external* costs (E) for the respective links. These then are the optimal congestion charges (EMCC).

If one does not wish to calculate optimal congestion charges in the way considered above, it should be noted that SATURN does yet allow for the implementation of road pricing. These link-specific tolls must generally be additive and can be charged in either a distance-based or a cordon-based manner.

Making use of that feature, the way that SATURN can be applied in order to determine link-specific and distance-based optimal congestion charges would be to build an algorithm around the software that iterates through repeated traffic assignments and adaptations of the tolls. First, one needs to supply SATURN with the network specifications and the trip matrix, as always. The assignment module will then calculate the first set of flows for zero tolls. Then, as in every other iteration, the information about the flows on the links is used to calculate the marginal external congestion costs (E) for the given flows outside of SATURN. If these are greater than the current toll on the respective link,

[18] In the SATURN manual f is denoted as v, $\bar{f}$ as c, and $\bar{t}$ as t_c.

the toll is increased. If these are less than the current toll, the toll is decreased. Then another iteration is executed with the altered tolls. The system will eventually converge to a situation where marginal external costs equal tolls on all links, indicating that the social optimum has been reached. These tolls are then the optimal congestion charges and the associated flows describe the corresponding traffic volume in the social optimum.

By the way, SATURN's feature called STOLL enabled the way that the perceptions of different individuals of the value of a fixed toll could be modelled as being stochastic.

Stochastic model

One can also input for the time-flow curves what is then interpreted as the marginal social cost expectation $d(F * C(F))/dF$, i.e. the marginal social cost curve for the private cost expectation $C(F)$ derived for the stochastic traffic model. Of course, the restriction on the functional form of those curves still applies. That means that essentially one has to give the marginal social cost expectation for a demanded flow of zero (t_0) and the exponent of the flow demand (n). And as above, it is recommended to assign to $\bar{f}$ a large value well above any values that could be expected for the demanded flow F, and $\bar{t}$ accordingly, to preclude horizontal segments in the relevant parts of the curves.

As for the deterministic case, it is worth noting that SATURN will output the equilibrium flows and the costs, with the latter being the marginal *social* cost expectations. The user of the software will need to manually calculate the optimal congestion charges (EMCC) by determining the marginal *external* costs (E) for the given flows, i.e. the differences between the marginal social cost expectations and the (average private) cost expectations $C(F)$.

The alternative method outlined for the deterministic model can also be applied in the stochastic case by supplying SATURN with the cost expectation functions $C(F)$ instead of deterministic time-flow curves. The construction of an iterative algorithm is analogous to the way described above.

A1-4. Parameters of the FORGE model

Table A-1: Values of working time per person in the FORGE model (€ per hour, 2010 prices)

Vehicle Occupant	Factor Cost	Market Price
Car driver	40.70	49.20
Car passenger	29.15	35.26
LCV/HGV driver	15.68	18.95
Bus driver	15.68	18.95
Bus passenger	31.13	37.64
Taxi driver	15.04	18.19
Taxi/Minicab passenger	68.83	83.20
Rail passenger	56.91	68.81
Underground passenger	55.37	66.93
Pedestrian	45.63	55.18
Cyclist	26.17	31.65
Motorcyclist	36.82	44.51

Table A-2: Values of non-working time per person in the FORGE model (€ per hour, 2010 prices)

Trip purpose	Factor Cost	Market Price
Commuting	7.76	9.38
Other	6.85	8.30

A2. Air delay costs

In this section some evidence on the values of air delay costs is reported, as calculated by Cook et al. (2004). All prices are of year 2000.

Table A-3: Tactical ground delay costs: at-gate and taxi (with network effect)

Aircraft and number of seats		Based on 15 minutes' delay			Based on 65 minutes' delay		
		Cost scenario			Cost scenario		
		Low	Base	High	Low	Base	High
B737-300	125	0.8	1.3	16.6	36.7	74.8	132.1
B737-400	143	0.9	1.3	18.0	42.5	84.7	148.4
B737-500	100	0.8	1.3	15.6	29.8	63.0	114.6
B737-800	174	0.8	1.2	19.6	51.1	99.7	171.6
B757-200	218	0.9	1.5	23.1	63.9	123.0	208.2
B767-300ER	240	1.1	1.8	31.5	70.5	142.8	249.1
B747-400	406	2.8	3.7	55.4	120.4	240.2	417.3
A319	126	0.8	1.3	16.6	37.2	75.5	133.8
A320	155	0.8	1.2	18.6	45.3	90.4	156.2
A321	166	0.9	1.4	19.0	48.9	95.8	164.2
ATR42	46	0.5	0.6	9.3	13.8	31.4	60.4
ATR72	64	0.5	0.8	10.6	19.1	40.9	75.1

All costs per minute, in Euro

Table A-4: Tactical airborne delay costs: en-route and holding (with network effect)

Aircraft and number of seats		Based on 15 minutes' delay			Based on 65 minutes' delay		
		Cost scenario			Cost scenario		
		Low	Base	High	Low	Base	High
B737-300	125	9.6	14.9	35.7	44.9	87.6	151.1
B737-400	143	9.2	14.3	36.4	50.6	97.3	167.0
B737-500	100	8.9	13.7	33.0	37.4	74.8	131.7
B737-800	174	7.8	12.5	35.1	58.9	112.1	188.6
B757-200	218	10.3	16.2	43.2	74.3	139.0	231.4
B767-300ER	240	14.2	22.5	60.1	85.1	165.7	282.7
B747-400	406	27.7	42.3	107.6	149.9	285.4	489.6
A319	126	7.1	11.2	30.7	44.4	86.6	150.9
A320	155	7.7	12.0	34.1	52.7	102.0	174.3
A321	166	9.5	14.9	38.2	57.9	109.8	185.3
ATR42	46	1.7	2.6	11.5	15.1	33.5	62.8
ATR72	64	2.2	3.4	13.7	21.0	43.9	79.0

All costs per minute, in Euro

Table A-5: Marginal cost of delay equations (econometric estimates, measure of fit R^2)

Base cost scenario based on:	Marginal cost of delay equation	R^2
'short' (15 minutes') at-gate delay	cost per min = [(0.004 x seats) + 0.31] Euros	0.90
'short' (15 minutes') airborne delay	cost per min = [(0.10 x seats) – 1.67*] Euros	0.92
'long' (65 minutes') at-gate delay	cost per min = [(0.57 x seats) + 2.53*] Euros	1.00
'long' (65 minutes') airborne delay	cost per min = [(0.69 x seats) – 1.49*] Euros	0.99

Annex B. Accident costs

Table B-1: Number of fatalities in road transport accidents

	Reporting year	Total	Car	Bus	HGV	LCV	Motor-cycle	Moped
AT	2010	452	291	8	7	10	68	18
BE	2009	787	464	1	20	43	137	25
BG	2010	582	479	3	25	0	42	6
CY	2010	47	26	0	0	0	16	3
CZ	2010	636	403	3	27	18	92	7
DK	2010	211	135	0	2	14	22	11
DE	2010	3165	1840	32	87	75	635	74
EE	2009	75	54	2	6	0	2	3
ES	2010	1981	1194	5	71	116	386	99
FI	2010	237	159	0	9	9	18	9
FR	2010	3507	2117	4	65	146	734	248
GR	2010	1077	543	2	14	62	367	36
HU	2010	548	330	12	11	24	49	19
IE	2009	201	146	0	3	14	25	0
IT	2010	3476	1827	9	34	31	943	203
LV	2009	167	115	2	5	4	10	1
LT	2009	259	183	0	2	0	30	5
LU	2010	31	27	0	1	0	1	0
MT	2010	11	8	0	0	0	3	0
NL	2009	581	288	0	4	24	68	47
PL	2010	2672	1853	14	142	0	259	83
PT	2010	732	367	0	12	88	126	67
RO	2010	1508	973	10	12	73	59	114
SE	2009	324	229	0	3	7	47	11
SI	2010	82	44	0	1	2	17	0
SK	2010	245	171	0	19	1	27	0
UK	2009	1813	1123	16	13	42	472	16
EU27		**25407**	**15385**	**123**	**599**	**083**	**4655**	**1105**

Source: Statistical Pocketbook Transport (2012)

Table B-2: Recommended correction factors for underreporting

Vehicle type	Fatality	Serious injury	Slight injury
Car	1.02	1.25	2
Motorbike/Moped	1.02	1.55	3.2

Source: HEATCO (2005)

For busses and light and heavy duty the same correction factors as for cars are employed.

Table B-3. Social cost values reported in the Road Safety Knowledge System

in mln Euro	Fatal injury	Hospitalised	Slightly injured
Austria	1.76	0.24	0.02
Belgium	1.64	0.25	0.02
Czech Republic	0.46	0.25	0.02
Denmark	2.20	0.27	0.02
Estonia	0.45	0.52	0.01
Germany	1.04	0.11	0.04
Greece	1.88	0.22	0.04
Hungary	0.47	NA	NA
Ireland	2.13	0.27	0.02
Italy	1.43	0.18	0.01
Latvia	1.43	0.13	0.01
Luxembourg	2.33	0.36	0.02
Malta	1.00	0.13	0.01
The Netherlands	1.78	0.24	0.02
Poland	0.4-0.7	NA	NA
Portugal	0.80	0.11	0.07
Slovakia	0.32	0.10	0.01
Slovenia	0.70	0.06	0.01
Spain	0.12	0.14	0.01
Sweden	1.19	0.27	0.02
United Kingdom	1.82	0.24	0.02
EU27	**1.28**	**0.18**	**0.02**

Source: http://erso.swov.nl/safetynet/content/wp_1_care_accident_data.htm

Annex C. Air pollution costs

C1. Overview of literature sources

The Handbook-2008 chapters on air pollution heavily rely on the results from two main European studies, HEATCO and CAFÉ CBA, both of which used the results of the ExternE process. The results of ExternE represent a milestone with respect to the evaluation of external costs in Europe. Many later studies also base their assumptions on these results. In contrast, relatively few try to challenge them. Generally, this is explained by the extreme complexity of the research, especially on the part of natural sciences. Searching for new, and better, evidence would require substantial funding and joint efforts of different teams with supplementary expertise.

Overall, the results of the following recent[19] studies are seen as directly relevant to the survey (Table C-1):

Table C-1: Recent literature sources on air pollution effects[20]

Study or Publication	Core type of analysis	Relevant information contained
EU Projects and Programs		
ESCAPE (European Study of Cohorts for Air Pollution Effects): EU Seventh Framework Program, runtime 2008-2012.	Primary research	Results not yet available
EXIOPOL - A new environmental accounting framework using externality data and input-output tools for policy analysis: EU Sixth Framework Program, runtime 2007-2011.	Primary research, methodological guidelines, impact assessment	Valuation of mortality risks, toxicity of PM components
HEIMTSA (Health and Environment Integrated Methodology and Toolbox for Scenario Assessment): EU Sixth Framework Program, runtime 2007-2011.	Methodological guidelines, impact assessment	Valuation of health end-points, update of dose-response functions
INTARESE (Integrated Assessment of Health Risks of Environmental Stressors in Europe): EU Sixth Framework Program, runtime 2005-2010.	Methodological guidelines, impact assessment	Valuation of health end-points, update of dose-response functions
NEEDS (New Energy Externalities Developments for Sustainability): EU Sixth Framework Programme, runtime 2004-2008.	Primary research	Monetary valuation of mortality risks
TRANSPHORM (Transport related Air Pollution and Health Impacts): **EU Seventh Framework Programme, runtime 2010-2014.**	Primary research	Results not yet available
Other European studies		
CE Delft, **Infras**, **Fraunhofer ISI 2011**: External Costs of Transport in Europe. Update study for 2008. Commissioned by: International Union of Railways UIC.	Methodological guidelines	Update of the marginal costs values of the Handbook-2008
EEA 2013 (European Environment Agency): Road user charges for heavy goods vehicles (HGV): Tables with external costs of air pollution. EEA Technical Report 1/2013.	Impact assessment	Draft marginal cost values for HGV
EEA 2012 (European Environment Agency): Air Quality in Europe – 2012 Report. EEA Technical Report 4/2012.	Information for the public	Data on air pollution exposure
EEA 2011 (European Environment Agency): Revealing the costs of air pollution from industrial facilities in Europe. EEA Technical Report 15/2011.	Primary research	Damage cost estimates
EEA 2009 (European Environment Agency): EMEP/EEA air pollutant emission inventory guidebook 2009 - Technical guidance to prepare national emission inventories. EEA Technical Report 9/2009.	Methodological guidelines	Emission factors for vehicles

[19] The update of the Handbook concentrated on the evidence produced since 2007, although some older studies were also reviewed.

[20] Individual scientific articles from different strands of literature were not included in this overview. These will be cited below where necessary.

Study or Publication	Core type of analysis	Relevant information contained
ETC/ACC 2012 (European Topic Centre on Air and Climate Change): Estimating the contribution of commuting on exposure to particulate matter in European urban areas. ETC/ACC Technical Paper 2012/2.	Primary research	Exposure to pollutants in urban areas
ETC/ACC 2009 (European Topic Centre on Air and Climate Change): Assessment of the health impacts of exposure to $PM_{2.5}$ at a European level. ETC/ACC Technical Paper 2009/1.	Impact assessment	PM composition, mortality valuation
JRC 2011 (Joint Research Centre - Institute for Energy and Transport): Parameterisation of fuel consumption and CO_2 emissions of passenger cars and light commercial vehicles for modelling purposes. JRC Scientific and Technical Reports.	Primary research	Emission factors for vehicles
U.S. Studies		
HEI 2012 Bell M.L. 2012. Assessment of the Health Impacts of Particulate Matter Characteristics. Research Report 161. Health Effects Institute.	Primary research	Health impacts of PM components
HEI 2011 Katsouyanni K. et al. 2009. Air Pollution and Health: A European and North American Approach (APHENA). HEI Research Report 142. Health Effects Institute.	Primary research	Mortality and morbidity effects of PM_{10} and O_3
HEI 2010 HEI Panel on the Health Effects of Traffic-Related Air Pollution. 2010. Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects. HEI Special Report 17. Health Effects Institute	Literature survey	Summary of scientific evidence on quantifiable health effects
NPACT (National Particle Component Toxicity) Initiative, funded by the Health Effects Institute.	Primary research	Health impacts of PM components
Muller and Mendelsohn (2007):Measuring the damages of Air Pollution in the United States	Impact assessment	Marginal cost estimates
Other national studies[21]		
Denmark: CEEH 2011 (Centre for Energy, Environment and Health): Assessment of Health Cost Externalities of Air Pollution at the National Level using the EVA Model System. CEEH Scientific Report No 3.	Impact assessment	Marginal costs estimates, end-points valuation
UK: AEA 2006 (AEA Technology): Damage Costs for Air Pollution: Report to DEFRA (part of Air Quality Strategy Review)	Literature survey	Valuation of health end-points, dose-response functions
UK: COMEAP 2010 (Committee on the Medical Effects of Air Pollutants): The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom - A report by the Committee on the Medical Effects of Air Pollutants.	Impact assessment	Sensitivity analysis for the mortality risk, mortality valuation
UK: DEFRA 2011 (Department for Environment, Food and Rural Affairs): Air Quality Appraisal – Damage Cost Methodology. Interdepartmental Group on Costs and Benefits, Air Quality Subject Group.	Impact assessment	Damage costs estimates
Sweden: IVL 2009 (Swedish Environmental Research Institute): Quantification of population exposure to $PM_{2.5}$ and PM_{10} in Sweden 2005. IVL Report B1792.	Impact assessment	Marginal costs estimates, end-points valuation
Canada: Marbek Resource Consultants 2007: Evaluation of Total Cost of Air Pollution Due to Transportation in Canada. Final Report.	Impact assessment	Marginal costs estimates, end-points valuation
Germany: Maibach et al. (2007): Praktische Anwendung der Methodenkonvention: Möglichkeiten der Berücksichtigung externer Umweltkosten bei Wirtschaftlichkeitsrechnungen von öffentlichen Investitionen. Forschungsprojekt im Auftrag des Umweltbundesamtes.	Methodological guidelines	Marginal costs estimates, end-points valuation
Australia: NSW Department of Environment and Conservation 2005: Air Pollution Economics - Health Costs of Air Pollution in the Greater Sydney Metropolitan Region.	Impact assessment	Marginal costs estimates, end-points valuation

[21] Only those studies that are not part of larger projects

Study or Publication	Core type of analysis	Relevant information contained
Germany: UBA 2011 (Umweltbundesamt): Stand der Modellierungstechnik zur Prognose der NO2 Konzentrationen in Luftreinhalteplänen nach der 39. BImSchV. Texte 70/2011.	Literature survey	Emission factors for NO2
Studies by International Organisations		
OECD 2012 (Organisation for Economic Development and Cooperation): Mortality Risk Valuation in Environment, Health and Transport Policies.	Literature survey	Recommendations for mortality valuation
WHO 2012 (World Health Organisation): Health effects of black carbon. WHO Regional Office for Europe, Task Force on Health.	Literature survey	Health impacts of PM components

Box C-1. Literature sources for Table 13:

[1]: European Environment Agency (EEA) 2012: Air Quality in Europe – 2012 Report.

[2]: Perez et al. (2009): Size Fractionate Particulate Matter, Vehicle Traffic, and Case-Specific Daily Mortality in Barcelona, Spain. Environmental Science Technology 43, 4707 – 4714.

[3]: Brauer, M. et al. (2006): Traffic-Related Air Pollution and Otitis Media, Environmental Health Perspectives, Vol. 114, No. 9, pp. 1414-1418.

[4]: Gehring, U. et al. (2010): Traffic-related Air Pollution and the Development of Asthma and Allergies during the First 8 Years of Life, American Journal of Respiratory and Critical Care Medicine, No. 181, pp. 596-603.

[5]: WHO (2005): WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide - Global update 2005 - Summary of risk assessment, World Health Organisation.

[6]: Amigou, A. et al. (2011): Road Traffic and Childhood Leukaemia: The ESCALE Study (SFCE), Environmental Health Perspectives, Vol. 119, No. 4, pp. 566-572.

[7]: Fierro, A. et al. (2001): Adverse Health Effects of Exposure to Ambient Carbon Monoxide.

[8]: Peter Bickel und Rainer Friedrich (2005): ExternE - Externalities of Energy - Methodology 2005 Update, Institut für Energiewirtschaft und Rationelle Energieanwendung — IER Universität Stuttgart, Germany. EUR 21951.

[9]: EC4MACS - European Consortium for Modelling Air pollution and Climate Strategies (2012): Greenhouse Gases and Air Pollutants in the European Union. Baseline Projections up to 2030. EC4MACS Interim Assessment.

[10]: Lipfert, F.W. et al. (2006): $PM_{2.5}$ constituents and related air quality variables as predictors of survival in a cohort of U.S. military veterans. Inhalation Toxicology 18 (9): 645-657.

[11]: Willis A., Jerrett M., Burnett R. T. et al. (2003): The association between sulfate air pollution and mortality at the county scale: an exploration of the impact of scale on a long-term exposure study. Journal of Toxicology and Environmental Health. Part A, 66 (16-19): 1605-1624.

[12]: Levy, J.I. et al. (2011): A Meta-Analysis and Multisite Time-Series Analysis of the Differential Toxicity of Major Fine Particulate Matter Constituents. American Journal of Epidemiology 175 (11): 1091-1099.

Table C-2: Core impact functions (relative risk estimates) for PM used in different studies[22]

Effect\Study	CAFE CBA (2005b): EU		Müller and Mendelsohn (2006): USA		AEA (2006): UK		Marbek(2007): Canada		IVL (2009): Sweden		HEIMTSA (2011): EU	
	Pollutant	Source	Pollutant	Source	Pollutant	Source	Pollutant	Source	Pollutant	Source	Pollutant	Source
Chronic mortality (deaths)	$PM_{2.5}$: 6.00%	[1]	$PM_{2.5}$: 6.00%	[1]	$PM_{2.5}$: 6.00%	[1]	$PM_{2.5}$: 6.8%	[16]	PM_{10}: 4.3% PMpri[23]: 17% PMc[24]: 1.0% $PM_{2.5}$: 6.0%	[12] [13] [14] [1]	$PM_{2.5}$: 6.00%	[1]
Infant mortality (deaths)	PM_{10}: 4.00%	[2]									PM_{10}: 4.00%	[2]
Chronic bronchitis	PM_{10}: 7.00%	[3]	PM_{10}: 7.00%	[3]			$PM_{2.5}$: 13.2%	[17]	PM_{10}: 7.00%	[3]	PM_{10}: 22.0%	[9]
Respiratory hospital admissions	PM_{10}: 1.14%	[4]			PM_{10}: 0.80%	[18]	$PM_{2.5}$: 0.75%	[18]	PM_{10}: 1.14%	[4]	PM_{10}: 0.90%	[10]
Cardiac hospital admissions	PM_{10}: 0.60%	[4]			PM_{10}: 0.80%	[18]	$PM_{2.5}$: 0.71%	[18]	PM_{10}: 0.38%	[15]	PM_{10}: 0.60%	[4]
Restricted activity days	$PM_{2.5}$:4.75%	[5]					$PM_{2.5}$: 4.81%	[18]	$PM_{2.5}$: 4.75%	[5]	$PM_{2.5}$: 4.75%	[5]
Respiratory medication (bronchodilator) use by adults	PM_{10}: 0.50%	[6]					$PM_{2.5}$: 0.79%	[19]			PM_{10}: 0.50%	[6]
Respiratory medication (bronchodilator) use by children	PM_{10}: 0.40%	[6]									PM_{10}: 0.40%	[6]
LRS, including cough (adults)	PM_{10}: 1.20%	[11]					$PM_{2.5}$: 2.66%	[20]			PM_{10}: 1.20%	[11]
LRS, including cough (children)	PM_{10}: 3.40%	[7]									PM_{10}: 3.40%	[7]
Work loss days											$PM_{2.5}$: 4.60%	[5]
Minor restricted activity days											$PM_{2.5}$: 7.40%	[8]
Child acute bronchitis episodes							$PM_{2.5}$: 27.2%	[21]				

Notes on health effects:

- *Chronic mortality: change in annual mortality rate per 10 µg/m3 PM2.5 (adults aged over 30)*
- *Infant mortality: change in infant mortality rate per 10 µg/m3 PM10 (mean outdoor concentration in the first two months of life)*
- *Chronic bronchitis: change in new persistent cases per year per 10 µg/m3 PM10 (adults aged over 27)*
- *Respiratory hospital admissions: change in attributable emergency admissions per 10 µg/m3 PM10 (all ages)*
- *Cardiac hospital admissions: change in attributable emergency admissions per 10 µg/m3 PM10 (all ages)*
- *Restricted activity days (RAD): change in RADs per year per 10 µg/m3 PM2.5 amongst the working age population (18-64 years)*
- *Respiratory medication use by adults: change in probability of daily bronchodilator usage per 10 µg/m3 PM10 (adults aged 20+ with well-established asthma)*
- *Respiratory medication use by children: change in probability of daily bronchodilator usage per 10 µg/m3 PM10 (children aged 5-14)*
- *LRS (adults): increase in daily average occurrence of LRS (including cough) per 10 µg/m3 PM10 among adults with chronic respiratory symptoms*
- *LRS (children): increase in daily average occurrence of LRS (including cough) per 10 µg/m3 PM10 among children (general population, aged 5-14)*
- *Work loss days: similar to RAD*
- *Minor restricted activity days: similar to RAD*

[22] Original literature sources for the relative risk estimates are reported in brackets and are listed in Box C-2.
[23] Primary combustion particles
[24] Coarse particles: PM_{10}- $_{2.5}$ fraction

Box C-2: Literature Sources for Table C-2:

[1]: Pope C. A., Burnett R. T., Thun M. J., Calle E. E., Krewski D., Ito K., Thursten G. D. (2002): Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. Journal of the American Medical Association, 287(9): 1132-1141.

[2]: Woodruff T.J., Grillo J. and Schoendorf K.C. (1997): The Relationship between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States. Environmental Health Perspectives, 105 (6): 608-612.

[3]: Abbey D.E., Hwang B.L., Burchette R.J., Vancuren T., Mills P.K. (1995a): Estimated long-term ambient concentrations of PM_{10} and development of respiratory symptoms in a nonsmoking population. Archives of Environmental Health, 50: 139-152.

[4]: APHEIS (Air Pollution and Health: A European Information System; 2004): Health impact assessment of air pollution and communication: Third Year Report, 2002-2003 (Apheis- 3).

[5]: Ostro B.D. (1987). Air pollution and morbidity revisited: A specification test. Journal of Environmental Economics and Management 14, 87-98.

[6]: WHO (World Health Organisation; 2004): Meta-analysis of time-series studies and panel studies of Particulate Matter (PM) and Ozone (O_3): Report of a WHO task group.

[7]: Ward D.J., Ayres J.G. (2004): Particulate air pollution and panel studies in children: a systematic review. Occupational and Environmental Medicine, 61(4): e13.

[8]: Ostro B.D. and Rothschild S. (1989): Air pollution and acute respiratory morbidity: An observational study of multiple pollutants. Environmental Research 50, 238-247.

[9]: Schindler C., Keidel D., Gerbase M.W., Zemp E., Bettschart R., Brändli O., Brutsche M.H., Burdet L., Karrer W., Knöpfli B., Pons M., Rapp R., Bayer-Oglesby L., Künzli N., Schwartz J., Liu L.-J.S., Ackermann-Liebrich U., Rochat T. and the SAPALIDA Team (2009): Improvements in PM_{10} exposure and reduced rates of respiratory symptoms in a cohort of Swiss adults (SAPALDIA). American Journal of Respiratory and Critical Care Medicine, 179: 589-587.

[10]: Hoek G., Boogaard H., Knol A., de Hartog J.J., Slottje P. Ayres J.G. et al. (2010): Concentration response functions for ultrafine particles and all-cause mortality and hospital admissions: results of a European expert panel elicitation. Environmental Science Technology 2010: 44: 476-482.

[11]: Hurley F., Hunt A., Cowie H., Holland M., Miller B., Pye S., Watkiss P. (2005): Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme- Methodology for the Cost-Benefit analysis for CAFE: Volume 2: Health Impact Assessment.

[12]: Medina S., Plasencia A., Ballester F., Mücke H.G., Schwartz J. (2004): Apheis group. Apheis: public health impact of PM_{10} in 19 European cities. Journal of Epidemiology and Community Health, 58(10): 831-6.

[13]: Jerrett M., Burnett R.T., Ma R., Pope C.A. 3rd, Krewski D., Newbold K.B., Thurston G., Shi Y., Finkelstein N., Calle E.E., Thun M.J. (2005): Spatial analysis of air pollution and mortality in Los Angeles, Epidemiology 16(6): 727-36.

[14]: Zanobetti A., Schwartz J., Samoli E., Gryparis A., Toulomi G., Atkinson R., Le Tertre A., Bobros J., Celko M., Goren A., Forsberg B., Michelozzi P., Rabczenko D., Ruiz E.A., Katsouyanni K. (2002): The temporal pattern of mortality responses to air pollution: A multicity assessment of mortality displacement, Epidemiology 13: 87-93.

[15]: COMEAP (2006): Cardiovascular Disease and Air Pollution - A report by the Committee on the Medical Effects of Air Pollutants, UK Department of Health, 2006.

[16]: Krewski D., Burnett R. T., Goldberg M. S., Hoover K., Siemiatycki J., Jerrett M., Abrahamowicz M., White W. H. (2000): Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of particulate air pollution and mortality. A special report of the Institute's particle epidemiology reanalysis project. Cambridge, MA: Health Effects Institute.

[17]: Abbey D.E., Ostro B.E., Petersen F., Burchette R.J. (1995b): Chronic respiratory symptoms associated with estimated log-term ambient concentrations of fine particulates less than 2.5 micron in aerodynamic diameter ($PM_{2.5}$) and other air pollutants. Journal of Exposure Analysis and Environmental Epidemiology, 5 (2): 137-159.

[18]: Burnett, R.T., Dales, R., Krewski, D., Vincent, R., Dann, T., Brook, J.R. (1995): Associations between ambient particulate sulfate and admissions to Ontario hospitals for cardiac and respiratory diseases. American Journal of Epidemiology. 142: 15-22.

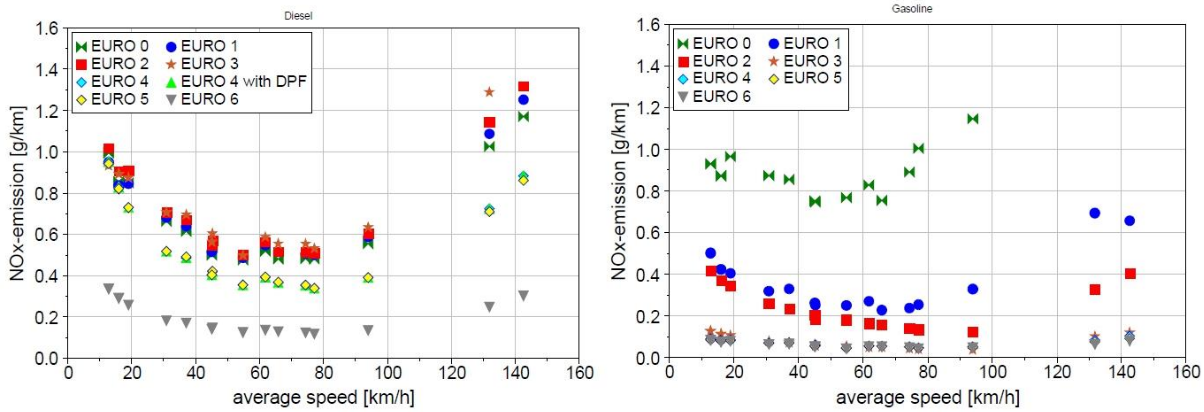
[19]: Ostro, B., Lipsett, M.J., Wiener, M.B., Selner, J.C. (1991): Asthmatic Responses to Airborne Acid Aerosols. American Journal of Public Health, 81(6): 694-702.

[20]: Krupnick A.J., Harrington W., Ostro B. (1990): Ambient ozone and acute health effects: Evidence from daily data. Journal of Environmental Economics and Management 18, 1-18.

[21]: Dockery D.W., Cunningham J., Damokosh A.I., Neas L.M., Spengler J.D., Koutrakis P., Ware J.H., Raizenne M., Speizer F.E. (1996): Health Effects of Acid Aerosols on North American Children: Respiratory Symptoms, Environmental Health Perspectives, 104(5): 500-505.

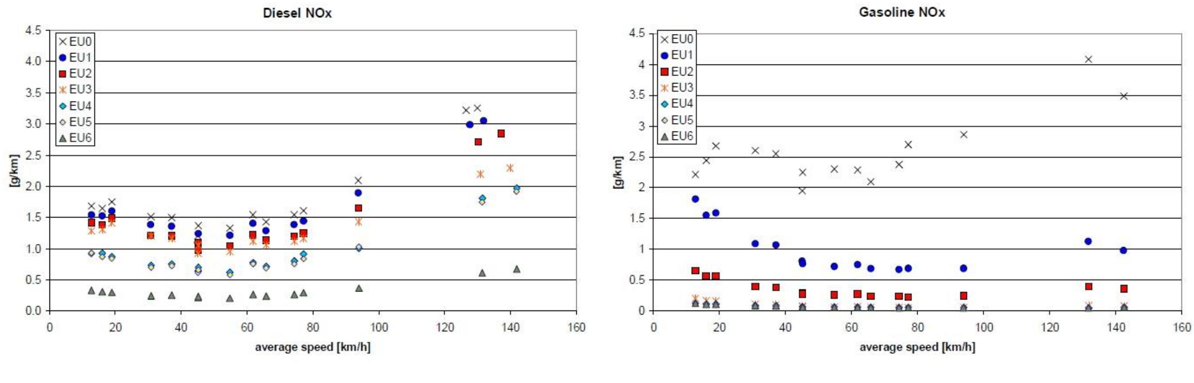
C2. Illustration of variations in emission factors

Figure C-1: Specific NO_x emissions for an average passenger car



Source: Eichlseder et al. (2009): Emission Factors from the Model PHEM for the HBEFA Version 3

Figure C-2: Specific NO_x emissions for an N1-type van



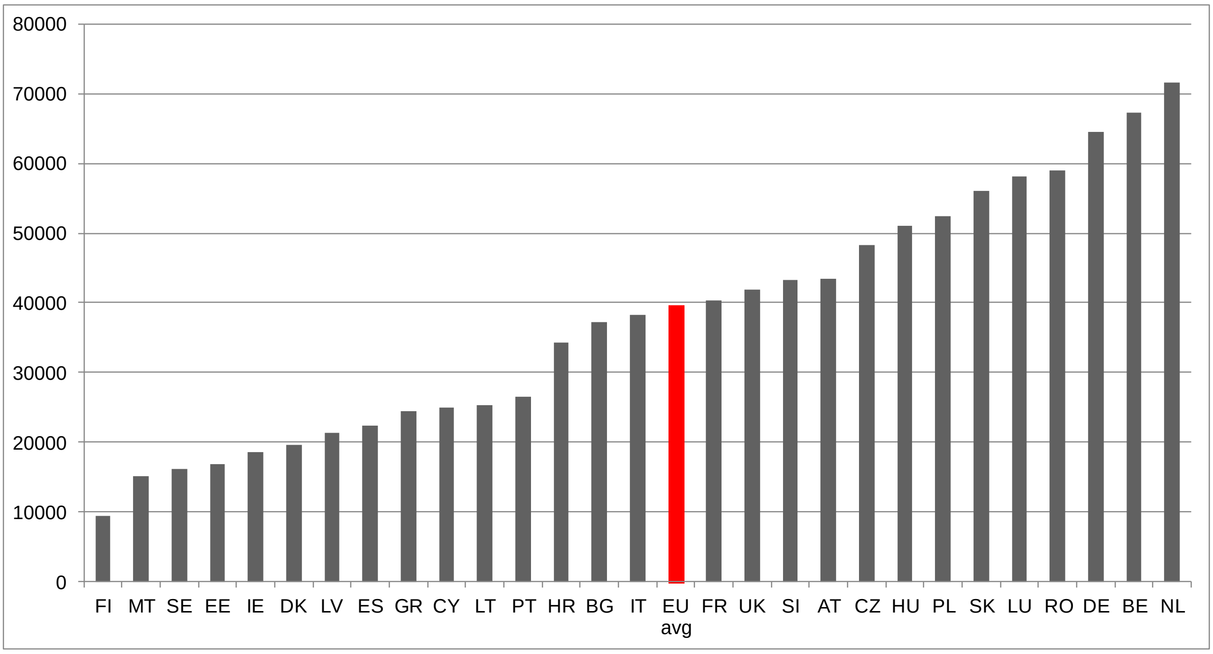
Source: Eichlseder et al. (2009): Emission Factors from the Model PHEM for the HBEFA Version 3

C3. Calculation of area-specific damage costs for PM.

The basis for the calculation is given by the values from the EcoSense model calculated for the NEEDS project (Preiss et al., 2008). These damage cost values relate to average population density in different countries. In the original report, they are valued in € of 2000. The advantage of these estimates is the complete coverage of all Europe, including marine territories, as well as the inclusion of material damage and agriculture effects, in addition to main health effects.

The results show very large variations in damage per tonne of emission between countries. Generally, the highest damages correspond to emissions in central Europe and in very urbanised countries like Belgium and the Netherlands, while the lowest correspond to emission in countries around the edges of Europe. This simply reflects variation in exposure of people and crops to the pollutants of interest – emissions at the edges of Europe will affect fewer people than emissions at the centre of Europe.

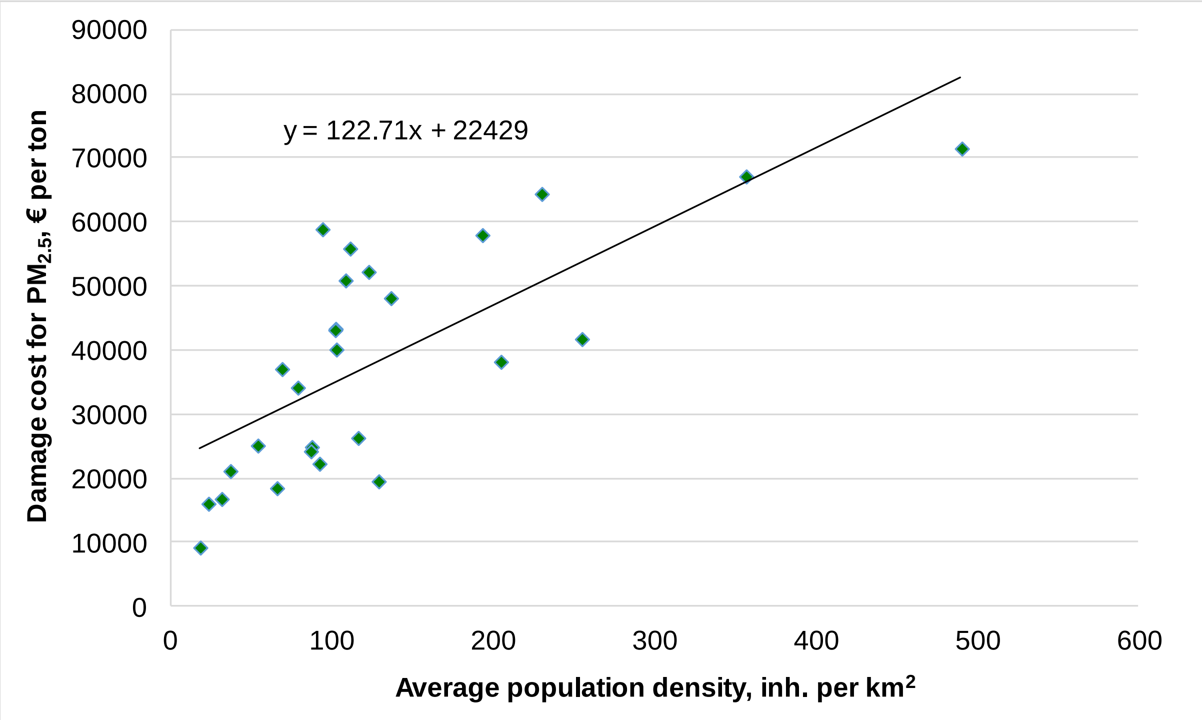
Figure C-3: $PM_{2.5}$ damage costs for transport emissions, € per tonne $PM_{2.5}$ (2010)



Source: Preiss et al. (2008, Excel annex) updated to € of 2010 using GDP per capita (PPP) figures.

Figure C-4 maps the country-specific damage costs of $PM_{2.5}$ as calculated by Preiss et al. (2008) against the average population density (2010) in the EU member states (excluding Malta, which is a single urban area according to Eurostat definition). The result is an upward trend with a high correlation coefficient. A very simple way to generate damage cost numbers for areas with density lower than average (rural areas) or higher than average (urban areas) would be to use the slope of this linear trend.

Figure C-4: Correlation between population density and PM damage costs



In order to calculate area- and country-specific damage costs, the data on population density from Eurostat was used.

For rural areas (NUTS3 regional level), the population density in the EU ranges between 9 inh./km^2 in Finland and 146 inh./km^2 in the Netherlands. The EU average population density for rural regions is 47 inh./km^2. These numbers are used in the following formula to calculate the country-specific damage costs of PM in rural areas:

$Cost_c^{rur} = Cost_c^{avg} + 122.7 * (Dens_c^{rur} - Dens_c^{avg})$, where

$Cost_c^{avg}$ is the average damage cost in country *c* taken from by Preiss et al. (2008)

$Dens_c^{rur}$ is the country-specific rural population density

$Dens_c^{avg}$ is the country-specific average population density

Thus, the estimated slope of the trend line in Figure C-4 is applied to every point on the graph, which represents a combination of $Cost_c^{avg}$ and $Dens_c^{avg}$. This is done in order to preserve a country-specific element in the calculation.

The only exceptions are Malta and Cyprus. For Malta, only a value for the urban territory can be defined. For Cyprus the formula $Cost_c^{rur} = Cost_c^{avg}$ is applied due to lacking detail from Eurostat on the population density by area type.

For intermediate and urban NUTS3 regions, the ranges of population density across countries are much wider than for rural areas, which is mostly explained by the way the NUTS3 regions in different countries are defined. In order to produce comparable results for different member states it is suggested to define thresholds for suburban and urban areas, common for all member states. These thresholds can be defined, using the data on population densities in urban areas as well as the definitions used in urban-rural typology of Eurostat.

The urban-rural typology[25] defines an "urban cluster" cell by a density of at least 300 inh./km^2 (grid cells with lower density are "rural"), while an "urban centre" cell must have at least 1500 inh./km^2. A suburban area must then have less than 50% of population leaving in "urban centres", and also less than 50% - in rural grid cells. A city must have more than 50% of population leaving in "urban centres".

[25] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Urban-rural_typology

This gives us a tentative range for the thresholds: for suburban area, the population density will be between 150 and 900 inh./km^2, while for urban area (city), 900 inh./km^2 would be the minimum.

Further information can be inferred from Eurostat data on population density in core **cities** and in **larger urban zones**, which are collected in the process of Urban Audit. The larger urban zone includes the city and its commuting zone[26]. These data suggest that median population density in the larger urban zones is 300 inh./km^2, while median population density in the core cities is 1500 inh./km^2. These values are in the tentative ranges calculated above and it is suggested to use them as reference values to define a representative suburban area and a representative urban area in the EU.

The PM damage costs for suburban and urban areas will then be calculated as follows:

$$Cost_c^{sub} = Cost_c^{sub} + 122.7 * (300 - Dens_c^{sub}),$$

$$Cost_c^{urb} = Cost_c^{urb} + 122.7 * (1500 - Dens_c^{urb}),$$

where the reference values defined above replace the country-specific values for population density in the suburban and urban zones. The resulting values are reported in Table 15 of the main text.

It is difficult to define an appropriate damage cost value for Malta. In the population statistics, it is treated as a single urban area with a high population density (>1300 inh per km^2). However, the damage cost value provided by Preiss et al. (2008) or, more recently, Brandt et al. (2010) do not seem to take account of this fact of high population density. Therefore, for Malta, we suggest to keep the value for the urban territory from the Handbook-2008.

[26] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Territorial_typologies_for_European_cities_and_metropolitan_regions

Annex D. Noise costs

D1. Overview of literature sources

Table D-1: Recent literature sources on noise effects

Study or Publication	Transport modes covered	Core type of analysis	Relevant information contained
EU Projects and Programs			
HEIMTSA (Health and Environment Integrated Methodology and Toolbox for Scenario Assessment): Literature review of theoretical issues and empirical estimation of health end-point unit values: noise case study. EU Sixth Framework Program, runtime 2007-2011.	Road, rail, aircraft	Methodological guidelines, impact assessment	Valuation of health end-points
Other European studies			
Andersson and Ögren (2008): Road noise charges based on the marginal cost principle.	Rail	Methodological guidelines	Methodology to evaluate marginal costs & suggestions for implementation of external costs
Babisch (2011): Quantifying the impact of noise on wellbeing and health.	-	Survey	Survey of research & policy in Europe
CE Delft, **Infras**, **Fraunhofer ISI** (**2011**): External Costs of Transport in Europe. Update study for 2008. Commissioned by: International Union of Railways UIC.	Road, rail	Methodological guidelines	Update of the marginal costs values (price level) of the Handbook-2008 for road and rail
Nijland and van Wee (2008): Noise valuation in ex-ante evaluation of major road and railroad projects.	Road, rail	Policy survey	Review of marginal cost evaluation methodology in Europe
North American Studies			
VTPI (2012): Transportation Cost and Benefit Analysis II – Noise Costs.	Road, rail	Literature survey	Marginal cost estimates
Nelson (2008): Hedonic Property Value Studies of Transportation Noise: Aircraft and Road Traffic	Aircraft	Literature survey	Hedonic valuation
Other national studies[27]			
Belgium/Flanders: Delhaye et al. (MIRA) (2010): Internalisation of external costs in Flanders.	Road (car, LGV, HGV, bus, MC), rail, inland waterways, sea transport	Primary research	Marginal cost and degree of internalisation
Belgium/Flanders: MIRA (2007): Milieurapport Vlaanderen.	Road, rail, aircraft	Primary research	Exposure to noise emission
France: Can et al. (2008): Dynamic estimation of urban traffic noise: influence of traffic and noise source representation.	Road	Methodological guidelines	Review of methodologies
Germany: Püschel and Evangelinos (2012): Evaluating noise annoyance cost recovery at Düsseldorf International Airport	Aircraft	Primary research	Hedonic valuation
Greece: Paviotti and Vogiatzis (2012): On the outdoor annoyance from scooter and motorbike noise in the urban environment.	Road (MC)	Primary research	Noise emission values

[27] Only those studies that are not part of larger projects

Study or Publication	Transport modes covered	Core type of analysis	Relevant information contained
Japan: Yamamoto (2010): Road traffic noise prediction model "ASJ RTN-Model 2008": Report of the Research Committee on Road Traffic Noise.	Road (LGV, MGV, HGV, MC)	Methodological guidelines, Primary research	Noise emission model
Netherlands: Dekkers and Straaten (2009): Monetary valuation of aircraft noise; a hedonic analysis around Amsterdam airport	Aircraft	Primary research	Marginal benefits of noise reduction, hedonic valuation
Sweden: Trafikverket (2012): Samhällsekonomiska principer och kalkylvärden för transportsektorn: ASEK 5	Road, Rail	Primary research	Noise damage costs
Sweden: Andersson et al. (2010): Benefit measures for noise abatement: calculation for road and rail traffic noise	Road, rail	Primary research	Monetary social values for noise abatement
Sweden: Andersson and Ögren (2013): Charging the polluters: A pricing model for road and railway noise	Road, rail	Methodological guidelines, Primary research	Marginal cost methodology & estimates
Sweden: Andersson and Ögren (2009): Noise Charges in Road Traffic: A Pricing Schedule Based on the Marginal Cost Principle.	Road (car, HGV)	Primary research	Marginal cost estimates
Sweden: Ögren and Andersson (2008): Road noise charges based on the marginal cost principle.	Road (car, HGV), rail	Primary research	Marginal cost estimates
Sweden: Vierth et al. (2008): The effect of long and heavy trucks on the transport system - Report on government assignment	Road (HGV)	Primary research	Marginal cost estimates of HGV
Sweden: Ögren et al. (2011): Noise charges for Swedish railways based on marginal cost calculations.	Rail	Primary research	Marginal cost estimates & policy implications
Switzerland: Boes et al. (2012): Aircraft noise, Health, and Residential Sorting: Evidence from two Quasi-Experiments	Aircraft	Primary research	Noise damage costs, Valuation of health end-points
Switzerland: Boes and Nüesch (2010): Quasi-experimental evidence on the effect of aircraft noise on apartment rents	Aircraft	Primary research	Hedonic valuation
UK: CE Delft et al. (2011): Ban on night flights at Heathrow Airport	Aircraft	Primary research	Noise damage costs
UK/Netherlands: Lu and Morrel (2006): Determination and applications of environmental costs at different sized airports – aircraft noise and engine emissions.	Aircraft	Methodological guidelines, Primary research	Marginal costs estimates
UK/France/Romania: Wardman and Brostow (2004): Using Stated Preference to Value Noise from Aircraft in three European Countries.	Aircraft	Primary research	Stated preference valuation of noise
UK: Nellthorp et al. (2007): Introducing willingness to pay for noise changes into transport appraisal - an application of benefit transfer	Road, rail	Methodological guidelines, Primary research	Evidence on discussion of road vs. rail noise
Various countries: Sandberg (2009): The global experience in using low-noise road surfaces: A benchmark report	Road	State-of-the-art review & policy recommendation	Road surface effect on noise
Studies by International Organisations			
WHO (2011) (Word Health Organisation): Burden of disease from environmental noise - Quantification of healthy life years lost in Europe	-	Methodological guidelines	Total damage costs, end-points valuation

D2. Input values used in 2008 Handbook

Table D-2: Parameters for the bottom-up estimation of road noise costs

Type of area	Time of day	Traffic density	Traffic volume	Share of HGV	Average speed	Distance to road	Settlement density	Density of inhabitants
Unit			*veh/h*	*%*	*km/h*	*metres*	*%*	*inhab./km road*
Rural	Day	Thin	2400	15%	120	100	10%	500
		Dense	6900	15%	120	100	10%	500
	Night	Thin	2400	15%	120	100	10%	500
		Dense	6900	15%	120	100	10%	500
Suburban	Day	Thin	1200	10%	80	20	50%	700
		Dense	4800	10%	80	20	50%	700
	Night	Thin	1200	10%	80	20	50%	700
		Dense	4800	10%	80	20	50%	700
Urban	Day	Thin	800	5%	40	10	100%	3000
		Dense	2650	5%	40	10	100%	3000
	Night	Thin	800	5%	40	10	100%	3000
		Dense	2650	5%	40	10	100%	3000

The values for rail traffic are based on the STAIRRS (2002) model. The most important input parameters to this model are presented in the table below:

Table D-3: Parameters for the bottom-up estimation of rail noise costs.

Type of area	Time of day	Traffic density	Traffic volume	Share of freight trains	Distance to track	Density of inhabitants	Affected inhabitants
Unit			*trains/h*	*%*	*metres*	*inhab./km track*	*inhab./km track*
Rural	Day	Thin	6	16.7%	300	500	50
		Dense	20	30%	300	500	50
	Night	Thin	4	50%	300	500	50
		Dense	11	45%	300	500	50
Suburban	Day	Thin	6	16.7%	100	700	350
		Dense	20	30%	100	700	350
	Night	Thin	4	50%	100	700	350
		Dense	11	45%	100	700	350

D3. Top-down procedure to calculate average noise costs

The source of population exposure data is the NOISE database:

Table D-4. Number of people exposed to noise from major roads outside agglomerations.

		Nr of people exposed to different noise bands (Lden)							
		Outside agglomerations					Including agglomerations		
Country Code	Major roads, km	*55-59*	*60-64*	*65-69*	*70-74*	*>75*	*>55*	*>65*	*>75*
France	12,624	3,840,000	1,904,100	1,253,100	653,500	211,000	7,772,600	2,044,200	197,200
Germany	12,286	1,498,400	551,800	249,000	131,200	36,400	3,786,500	821,600	47,600
United Kingdom	11,527	5,052,500	3,223,200	1,318,800	412,500	80,000	15,363,300	2,461,200	136,500
Spain	7,896	1,217,700	589,100	290,600	136,500	69,000	2,897,500	642,700	86,800
Italy	7,568	1,654,800	1,382,600	910,400	370,500	121,100	4,669,500	1,424,800	133,400
Netherlands	3,503	128,600	43,600	13,200	1,900	100	802,100	52,800	300
Belgium	2,792	477,100	223,500	133,300	133,700	24,100	1,186,300	395,500	39,700
Austria	2,453	464,000	185,500	84,600	42,300	2,100	778,500	129,000	2,100
Poland	2,425	211,000	110,900	59,900	36,800	18,100	443,400	119,800	18,400
Portugal	1,743	8,500	3,800	1,000	200	0	12,800	1,200	0
Sweden	1,318	245,600	106,800	49,000	15,200	4,800	554,000	98,000	9,700
Czech Republic	1,243	363,800	181,400	116,900	60,500	32,200	1,052,800	338,100	38,500
Denmark	1,043	77,200	45,600	23,500	13,600	400	405,400	114,700	3,700
Norway	950	55,400	34,300	20,500	13,800	7,600	191,100	63,500	8,700
Finland	647	63,100	27,000	9,400	2,100	400	142,400	18,600	400
Ireland	564	54,500	23,100	12,400	6,400	1,200	607,400	180,000	15,000
Hungary	539	61,100	42,700	53,400	14,000	1,000	759,400	663,500	87,500
Slovenia	457	77,400	29,900	17,900	10,400	700	136,300	29,000	700
Slovakia	401	82,800	54,200	22,800	14,700	9,900	444,900	136,800	37,200
Cyprus	321	25,100	16,500	8,100	9,300	900			
Romania	268	22,700	15,400	21,900	5,700	1,100	81,300	28,200	3,200
Luxembourg	128	7,100	2,000	1,000	200	0	10,400	1,200	0
Lithuania	123	4,300	1,800	1,200	300	0	22,300	4,000	100
Bulgaria	89	500	200	100	100	100	5,200	1,000	100
Malta	84	8,800	6,100	5,700	2,600	100	23,200	8,300	100
Iceland	45	7,600	6,500	6,000	3,700	600	24,100	10,000	300
Latvia	36	1,100	400	0	0	0	9,000	1,200	0
Estonia	11	100	0	0	0	0	0	0	0
Switzerland		749,600	325,000	126,000	19,100	200	5,410,200	829,800	12,300
Total EU 27		**15,710,800**	**8,812,000**	**4,683,700**	**2,091,700**	**622,900**	**42,181,700**	**9,788,900**	**867,200**
Total general		**16,460,400**	**9,137,000**	**4,809,700**	**2,110,800**	**623,100**	**47,591,900**	**10,618,700**	**879,500**

Source: ETC/LUSI(2013)

These numbers have to be multiplied by the (damage) cost factors for noise exposure, the main source for which remains the HEATCO study (relevant cost factors are provided in Deliverable 5, Annex E, Table 3.3). A price level update of original values has been carried out in accordance to country-specific development in GDP per capita. The resulting cost factors are provided in Table D-3.

Table D-5. Cost factors (central values) for noise exposure (€ 2010, factor costs, per year per person exposed)

	Lden, dB(A)					
Country	**=51**	**=55**	**=60**	**=65**	**=70**	**=75**
France	10	52	106	158	212	351
Germany	12	61	120	181	242	402
United Kingdom	12	59	120	179	238	397
Spain	8	39	78	117	156	259
Italy	9	45	90	135	180	298
Netherlands	12	62	125	187	249	414
Belgium	11	54	109	163	219	362
Austria	12	62	122	184	244	406
Poland	3	15	31	46	63	104
Portugal	6	29	56	84	113	187
Sweden	13	67	133	199	265	441
Czech Republic	4	19	38	57	76	127
Denmark	15	75	152	227	304	506
Finland	12	61	122	182	243	403
Ireland	14	69	137	206	274	456
Hungary	4	16	33	49	66	109
Slovenia	5	27	55	82	109	181
Slovakia	*3*	*15*	*29*	*44*	*58*	*97*
Cyprus	8	37	76	113	152	253
Romania	3	15	29	44	58	97
Luxembourg	19	92	185	276	369	613
Lithuania	3	12	25	37	49	83
Bulgaria	3	15	29	44	58	97
Latvia	3	13	26	39	52	86
Estonia	*3*	*15*	*32*	*48*	*63*	*105*

Source: Updated from HEATCO Deliverable 5, Annex E, Table 3.3

For distributing the total costs across different vehicle categories the same weighting factors as in Handbook-2008 were used:

Table D-6. Weighting factors for noise from different vehicle classes (on motorways)

Vehicle type	Weighting factor
Car	1.0
Motorcycle	4.2
LDV	1.2
Bus	3.3
HGV < 16t	3.0
HGV > 16t	4.2

Source: Handbook-2008, Table 21.

Annex E. Climate change costs

E1. Overview of literature sources

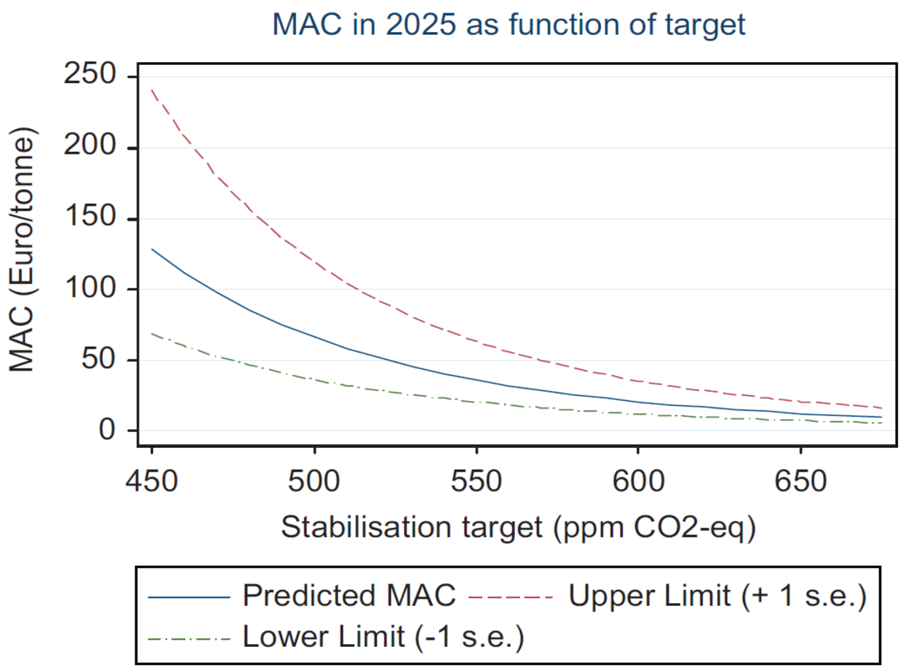
Table E-1: Recent literature sources on climate change costs

Study or Publication	Core type of analysis	Relevant information contained
EU Projects and Programs		
Kovats et al. (2011): Technical Policy Briefing Note 5: The Impacts and Economic Costs on Health in Europe and the Costs and Benefits of Adaptation	Primary Research	Overall costs in health sector
Hope, C. (2011a) The PAGE09 integrated assessment model	Summary of scenario use, application of PAGE09	Marginal damage cost values
European Studies[28]		
Kuik et al. (2009): Marginal abatement costs of greenhouse gas emissions: A meta-analysis.	Meta-analysis, literature survey	Marginal abatement costs
DECC (2009). Carbon Valuation in UK Policy Appraisal: a Revised Approach	Methodological guidelines	Marginal abatement cost
Musso et al. (2012). Internalisation of external costs of transport–A target driven approach with a focus on climate change.	Literature survey, methodological guidelines	Outline of the theoretical foundations
Hope (2011b): The social cost of CO2 from the PAGE09 model.	Methodological guidelines, use of PAGE09	Methodology, marginal damage cost
van Vuuren et al. (2011): RCP2. 6: exploring the possibility to keep global mean temperature increase below 2° C	Methodological discussion, Application of IMAGE scenarios	Marginal abatement costs
North American Studies[1]		
US Interagency Working Group on Social Cost of Carbon (2010) Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis	Application of DICE, PAGE and FUND	Marginal damage costs
Kopp et al. (2012) The US Government's Social Cost of Carbon Estimates after Their First Two Years: Pathways for Improvement.	Methodology review	Limitations of estimates from U.S. government report
Waldhoff et al. (2011). The marginal damage costs of different greenhouse gases: An application of FUND	Application of FUND, methodological guidelines	Marginal damage costs
Anthoff et al. (2011). Regional and sectoral estimates of the social cost of carbon: An application of FUND	Sensitivity analysis, application of FUND	Methodology, marginal damage cost
Cooke (2011). A Shapley-value approach to pricing climate risks	Methodological guidelines	Methodology. price of risk of climate change
Ackerman et al. (2011). Climate risks and carbon prices: Revising the social cost of carbon	Repeated analysis, application of DICE	Sensitivity analysis, marginal damage costs

[28] Only those studies that are not part of larger projects

E2. Carbon price estimates using alternative approaches

Figure E-1: Marginal CO_2 abatement cost (MAC) estimates of Kuik et al. (2009): €2005



Source: Kuik et al. (2009, Figure 2).

Table E-2: The mean and standard deviation of CO_2 damage cost (€/tonne) for a statistical distribution based on 232 published estimates

CO_2 damage cost	Sample of studies			
	All	Pure rate of time preference		
		0%	1%	3%
Mean	49	76	24	5
StDev	81	71	26	5
Mode	14	35	13	3
33%ile	10	35	10	2
Median	32	58	20	4
67%ile	59	93	32	7
90%ile	135	177	58	12
95%ile	185	206	72	15
99%ile	439	265	103	19

Source: Tol (2012, Table 1)

Annex F. Costs of up- and downstream processes

Table F-1. Share of electricity production by fuel type in 2009

Country	Coal and lignite (%)	Oil (%)	Natural and derived gas (%)	Renewables (%)	Nuclear (%)	Other fuels (%)
EEA	24	3	23	23	25	1
EU-27	25	3	23	20	27	2
Belgium	6	1	33	9	51	2
Bulgaria	48	1	5	10	35	1
Czech Republic	55	0	4	6	33	1
Denmark	49	3	19	30	0	0
Germany	42	2	14	17	22	3
Estonia	88	1	6	6	0	0
Ireland	23	3	57	15	0	1
Greece	55	12	18	14	0	1
Spain	12	6	36	26	17	3
France	5	1	4	14	75	1
Italy	13	9	51	25	0	2
Cyprus	0	99	0	0	0	1
Latvia	0	0	36	64	0	0
Lithuania	0	5	13	9	68	6
Luxembourg	0	0	61	22	0	16
Hungary	18	2	29	8	43	0
Malta	0	99	0	0	0	1
Netherlands	21	1	63	11	4	0
Austria	5	2	19	70	0	5
Poland	88	2	4	6	0	0
Portugal	25	6	29	38	0	2
Romania	37	2	13	27	20	0
Slovenia	31	0	4	30	35	0
Slovakia	15	2	9	20	53	1
Finland	22	1	14	30	33	1
Sweden	1	1	1	59	38	0
UK	28	1	44	8	18	1

Source: http://www.eea.europa.eu/data-and-maps/figures/share-of-electricity-production-by-7#tab-european-data

Table F-2. Pollution factors from energy production in g/GJ.

Pollutant	Hard Coal	Brown Coal	Coal (avrg)	Heavy Fuel Oil	Gas (avrg)	Natural Gas	Derived Gases	Other liquid fuels
NO_x	310.0	360.0	**335.0**	**215.0**	**114.5**	89.0	140.0	180.0
SO_x	820.0	820.0	**820.0**	**485.0**	**0.3**	0.3	0.3	460.0
NMVOC	1.2	1.7	**1.5**	**0.8**	**2.0**	1.5	2.5	0.8
$PM_{2.5}$	9.0	9.0	**9.0**	**13.0**	**3.0**	0.9	5.0	1.0
PM_{10}	20.0	20.0	**20.0**	**18.0**	**3.0**	0.9	5.0	2.0

Source: EMEP/EEA Guidebook on Energy (EMEP/EEA (2010b)).

Using data from Tables F-1 and F-2, we can calculate the emission factors induced by electricity use (e.g. by electric trains):

Table F-3. Emission factors from electricity use in g/GJ.

g/GJ	NOx	SO_2	NMVOC	$PM_{2.5}$	PM_{10}
EEA	*114.6*	*213.0*	*0.8*	*3.2*	*6.1*
EU-27	*119.4*	*225.4*	*0.9*	*3.4*	*6.4*
Belgium	58.4	49.6	0.8	1.6	2.2
Bulgaria	171.5	406.6	0.8	4.7	10.1
Czech Republic	192.8	459.1	0.9	5.2	11.3
Denmark	191.1	414.6	1.1	5.3	10.9
Germany	163.7	359.4	0.9	4.5	9.3
Estonia	301.0	720.5	1.4	8.1	17.8
Ireland	151.7	208.5	1.5	4.2	7.0
Greece	234.1	517.6	1.3	7.2	13.9
Spain	95.8	128.8	1.0	2.9	4.6
France	23.4	44.4	0.2	0.7	1.3
Italy	123.9	154.9	1.3	3.9	5.8
Cyprus	214.8	484.6	0.8	13.0	18.0
Latvia	41.5	0.8	0.7	1.1	1.1
Lithuania	26.4	23.7	0.3	1.0	1.3
Luxembourg	83.9	0.2	1.5	2.2	2.2
Hungary	96.4	153.5	0.9	2.7	4.7
Malta	215.0	485.0	0.8	13.0	18.0
Netherlands	146.3	182.1	1.6	3.9	6.4
Austria	44.4	52.8	0.5	1.3	2.0
Poland	303.0	729.8	1.4	8.3	18.0
Portugal	133.7	242.4	1.0	4.0	7.2
Romania	144.5	316.0	0.8	4.0	8.2
Slovenia	109.3	257.4	0.5	2.9	6.4
Slovakia	65.1	132.7	0.4	1.9	3.7
Finland	90.4	181.2	0.6	2.5	4.9
Sweden	5.7	9.9	0.0	0.2	0.3
UK	146.7	234.1	1.3	4.0	7.1

The corresponding damage costs are extracted from NEEDS (values for high height of release).

Table F-4. Damage costs for emissions from electricity production, € per tonne, prices of 2010.

	NMVOC	SO_2	NOx	$PM_{2.5}$
Country				
Austria	2000	11150	12950	21650
Belgium	3200	13100	10150	28600
Bulgaria	750	11650	11600	21850
Croatia	1800	13200	14000	25900
Cyprus	1100	12350	6350	18650
Czech Republic	1600	13350	13150	27950
Germany	1850	13600	13550	33750
Denmark	1500	6550	6100	10500
Estonia	1100	8150	4050	9800
Spain	1100	7450	4150	10700
Finland	750	4350	3050	4550
France	1650	10300	11100	23400
Greece	850	7550	3150	11400
Hungary	1550	13500	16050	30050
Ireland	1350	7300	4750	8400
Italy	1200	8700	8550	17300
Lithuania	1500	10150	9550	13900
Luxembourg	3500	16600	15000	33100
Latvia	1450	9250	7250	12450
Malta	1000	6650	3250	9300
Netherlands	2750	13550	9400	32650
Poland	1650	14200	10400	29400
Portugal	1000	4750	1300	6500
Romania	1750	16400	15850	30900
Sweden	950	5550	5050	5850
Slovenia	1950	13200	13400	22550
Slovakia	1700	16200	17000	31700
United Kingdom	1750	8450	5150	17500
European Union	**1550**	**9350**	**8050**	**18850**

Source: NEEDS (Preiss et al., 2008), values for high height of release, updated to year 2010 using country-specific nominal GDP per capita (PPP) figures.

Annex G. Infrastructure costs

G1. Overview of literature sources

Box G-1: Literature sources for Table 47:

[1]: Austroads (2012), Austroads research report - Preliminary methodology for estimating cost implications of incremental loads on road pavements, Ap-R402-12, Austroads Ltd, Sydney

[2]: Haraldsson, M. (2012), Marginalkostnader för drift och underhåll av det nationella vägnätet, VTI 29-2011, VTI, Stockholm

[3]: Trafikanalys (2011), Internalisering av trafikens externa effekter - nya beräkningar för väg och järnväg, 2011:6, Trafikanalys, Stockholm

[4]: GAO (2011), Surface freight transportation - a comparison of the costs of road, rail, and waterways freight shipments that are not passed on to consumers, GAO-11-134, GAO, Washington

[5]: ARRB (2010), Estimating the marginal cost of road wear on Australia´s sealed road network, working paper made for Austroads and National transport commission, ARRB, Melbourne

[6]: COWI (2010), Transportministeriet - værdisætning af transportens eksterne omkostninger, COWI, Lyngby, Denmark.

[7]: Johnson, L., Haraldsson, M. (2009), Marginal costs of road maintenance in Sweden, CATRIN - Deliverable D6, VTI, Stockholm

[8]: Bak, M., Borkowski, P. (2009), Marginal cost of road maintenance and renewal in Poland, CATRIN - Deliverable D6, University of Gdansk, Poland

[9]: Link, H. (2009), Marginal cost of road maintenance in Germany, CATRIN - Deliverable D6, DIW, Berlin.

[10]: Australian Government (2006), Road and rail freight infrastructure pricing, No. 41, Australian Government - Productivity commission, Melbourne.

G2. Calculation of ESAL factors for HGVs

The ESAL equivalents for HGVs are calculated based on the following formula:

$$N = \left(\frac{W_1}{10}\right)^4 + (A-1)\cdot\left(\frac{W-W_1}{10\cdot(A-1)}\right)^4,$$

where W_1 is the load on the first axle, W is the total load, A is the number of axles. The results are reported in Table G-1.

Table G-1. ESAL factors for different HGV categories.

Vehicle category	Load on first axle, tonnes	Total load tonnes	ESAL factor
HGV 3.5 - 7.5 t, 2 axles	3	5.5	0.01
HGV 7.5 - 12 t, 2 axles	3	10.0	0.25
HGV 12 - 18 t, 2 axles	7	15.0	0.65
HGV 18 - 26 t, 3 axles	7	22.0	0.87
HGV 26 - 32 t, 4 axles	7	29.0	1.11
HGV 26 - 32 t, 5 axles	7	29.0	0.61
HGV 32 - 40 t, 5 axles	7	36.0	1.35
HGV 32 - 40 t, 6 axles	7	36.0	0.81
HGV 40 - 50 t, 8 axles	7	45.0	0.85
HGV 40 - 50 t, 9 axles	7	45.0	0.65
HGV 50 - 60 t, 8 axles	7	55.0	1.79
HGV 50 - 60 t, 9 axles	7	55.0	1.28
HGV 40 t, 8 axles	7	40.0	0.59
HGV 40 t, 9 axles	7	40.0	0.47
HGV 44 t, 5 axles	7	44.0	3.17
HGV 44 t, 6 axles	7	44.0	1.74

G3. Road infrastructure cost estimates for selected countries

The Table below reports the estimates of marginal costs contained in CE Delft (2010).

Table G-2: Road infrastructure costs of trucks (€ct/vkm, price level 2007)

Country	Vehicle	Motorways			Interurban roads			Urban roads		
		Fixed	Vari-able	Total	Fixed	Vari-able	Total	Fixed	Vari-able	Total
France	HGVs	12.2	3.5	15.7	28.1	10	38.2	28.1	10	38.2
Belgium	HGV 40t	14.8	6.2	21	32.4	22.3	54.7	20.4	20.5	40.9
	Average truck	10	3.7	13.7	22.2	12.8	35	15.7	14.4	30.1
The Nether-lands	Solo truck > 12 tonne	10.8	2.3	13.1	22.1	8.2	30.3	15.1	7.8	22.9
	Truck combi-nation	13.8	5.8	19.6	29.8	20.5	50.3	18.8	18.9	37.7
	Average truck	12.5	4.5	17	24.6	14.2	38.8	17.4	16	33.3

G4. Railway infrastructure access charges

Table G-3: EU freight rail infrastructure access charges (in €), 2007- 2009

	Line Category	Calculated access charge (EUR/train-km)						
		Freight						
			960 tonnes		2,000 tonnes		3,000 tonnes	
		Res.	Usage	Total	Usage	Total	Usage	Total
Austria	Brenner		3.88	3.88	4.97	4.97	6.02	6.02
	Branch Lines		1.95	1.95	3.05	3.05	4.10	4.10
	Other International Lines		2.66	2.66	3.75	3.75	4.80	4.80
	Other Main Lines		2.25	2.25	3.34	3.34	4.39	4.39
	Westbahn		3.38	3.38	4.47	4.47	5.52	5.52
Belgium [a)]	All		1.65					
Bulgaria	Category I	2.46	3.36	5.82	5.57	8.03	7.69	10.15
	Category II	2.46	3.36	5.82	5.66	8.03	7.69	10.15
Czech Republic	European Rail System		4.83	4.83	7.76	7.76	10.58	10.58
	Other national		4.19	4.19	6.63	6.63	8.98	8.98
	Regional		3.43	3.43	5.26	5.26	7.02	7.02
Denmark	National Network		0.26	0.26	0.26	0.26	0.26	0.26
Estonia	All		6.55	6.55	9.54	9.54	12.41	12.41
Finland	All		2.14	2.14	4.45	4.45	6.68	6.68
France [a)]	A (hi traffic peri-urb)	5.14	0.47	5.61	0.47	5.61	0.47	5.61
	B (med traffic peri-urb)	1.48	0.47	1.95	0.47	1.95	0.47	1.95
	C/C* (hi traffic intercity)	0.77	0.47	1.24	0.47	1.24	0.47	1.24
	D/D* (med traffic intercity)	0.05	0.46	0.51	0.46	0.51	0.46	0.51
	E (all other)	0.01	0.46	0.46	0.46	0.46	0.46	0.46
	N1 (hi traffic hi speed)							
	N2 (med traffic hi speed)							
	N3 (lo traffic hi speed)							
	N4 (East Eur hi speed)							
Germany	F+ (long dist)							
	F1 (long dist)		6.80	6.80	6.80	6.80	6.80	6.80
	F2 (long dist)		2.85	2.85	2.85	2.85	2.85	2.85
	F3 (long dist)		2.53	2.53	2.53	2.53	2.53	2.53
	F4 (long dist)		2.42	2.42	2.42	2.42	2.42	2.42
	F5 (long dist)		1.86	1.86	1.86	1.86	1.86	1.86
	F6 (long dist)		2.18	2.18	2.18	2.18	2.18	2.18
	Z1 (feeder)		1.24	1.24	1.24	1.24	1.24	1.24
	Z2 (feeder)		1.29	1.29	1.29	1.29	1.29	1.29
	S1 (urban rapid)							
	S2 (urban rapid)							

	Line Category	Calculated access charge (EUR/train-km)						
		Freight						
			960 tonnes		2,000 tonnes		3,000 tonnes	
		Res.	Usage	Total	Usage	Total	Usage	Total
	S3 (urban rapid)							
Hungary	Category I		2.34	2.34	2.34	2.34	2.34	2.34
	Category II		1.43	1.43	1.43	1.43	1.43	1.43
	Category III		0.79	0.79	0.79	0.79	0.79	0.79
Italy [a)]	Line specific		2.41	2.41				
Latvia	All		6.57	6.57	6.57	6.57	6.57	6.57
Lithuania	All		6.50	6.50	11.38	11.38	16.07	16.07
Netherlands	All		2.14	2.14	3.94	3.94	5.67	5.67
Poland	0 to 40		3.55	3.55	4.62	4.62	5.64	5.64
	40 to 60				5.29	5.29	6.32	6.32
	60 to 80				6.01	6.01	7.04	7.04
	80 to 100				7.06	7.06	8.09	8.09
	100 to 120				9.73	9.73	10.76	10.76
	>120							
Portugal	GH1 (suburban)		1.44	1.44	1.44	1.44	1.44	1.44
	GH2 (suburban)		1.22	1.22	1.22	1.22	1.22	1.22
	GH3 (suburban)		2.22	2.22	2.22	2.22	2.22	2.22
	GH4		1.33	1.33	1.33	1.33	1.33	1.33
	GH5 (suburban)		1.43	1.43	1.43	1.43	1.43	1.43
	GH6 (electrified)		1.42	1.42	1.42	1.42	1.42	1.42
	GH7 (elect., mostly fr.)		1.10	1.10	1.10	1.10	1.10	1.10
	GH8 (non elect., lo density)		1.87	1.87	1.87	1.87	1.87	1.87
	Non-elect., RES block		1.56	1.56	1.56	1.56	1.56	1.56
Romania	All		3.93	3.93	3.93	3.93	3.93	3.93
Slovak Republic	Category I		9.55	9.55	10.31	10.31	11.04	11.04
	Category II		9.48	9.48	10.18	10.18	10.86	10.86
	Category III		6.63	6.63	7.22	7.22	7.79	7.79
Slovenia	Mean Lines (1.0 weight)		2.23	2.23	2.23	2.23	2.23	2.23
	Regional Lines (0.7 weight)		1.56	1.56	1.56	1.56	1.56	1.56
Spain [a)]	A1 Madrid/Barcelona, Cordoba/Malaga, Madrid/Valladolid							
	A2 Madrid/Sevilla, Tramo, LaSagra/Toledo, Zaragossa/Huesca							
	B1 Corredor Mediterraneo	0.32	0.06	0.38	0.06	0.38	0.06	0.38
	C1 Rest of system	0.32	0.06	3.80	0.06	3.80	0.06	3.80
Sweden	All		0.39	0.39	0.72	0.72	1.03	1.03

	Line Category	Calculated access charge (EUR/train-km)						
		Freight						
			960 tonnes		2,000 tonnes		3,000 tonnes	
		Res.	Usage	Total	Usage	Total	Usage	Total
United Kingdom [a)]	All		3.11	3.11	6.23	6.23	9.23	9.23
Croatia	Class 1		0.30	0.30	0.30	0.30	0.30	0.30
	Class 2		0.22	0.22	0.22	0.22	0.22	0.22
	Class 3		0.08	0.08	0.08	0.08	0.08	0.08
	Class 4		0.11	0.11	0.11	0.11	0.11	0.11
	Class 5		0.10	0.10	0.10	0.10	0.10	0.10
	Class 6		0.14	0.14	0.14	0.14	0.14	0.14

(a) These countries have time of day access charges. Number shown are for "normal" time. Off-peak charges can be half or less of "normal" and Peak charges can be twice or three times "normal".

Source: International Transport Forum: Charges of the Use of Rail Infrastructure, 2008, Table 5.

Table G-4: EU passenger rail infrastructure access charges (in €), 2007- 2009

	Line Category	Calculated access charge based on network statement (EUR/train-km)											
		Passenger											
		Regional, local, suburban				Intercity				High speed			
		Res.	Usage	Stat. stops	Total	Res.	Usage	Stat. stops	Total	Res.	Usage	Stat. stops	Total
Austria	Brenner		3.15	0.24	3.40		3.49	0.10	3.59				
	Branch Lines		1.23	0.35	1.58		1.57	0.06	1.62				
	Other International Lines		1.93	0.11	2.04		2.27	0.10	2.37				
	Other Main Lines		1.52	0.16	1.69		1.86	0.12	1.98				
	Westbahn		2.66	0.11	2.77		2.99	0.10	3.10				
Belgium [a)]	All		2.61		2.61		4.51				19.15		
Bulgaria	Category I	0.19	0.84		1.04	1.48	2.42		3.90				
	Category II	0.10	0.43		0.53	0.39	2.42		2.80				
Czech Republic	European Rail System		0.94		0.94		1.61		1.61				
	Other national		0.76		0.76		1.30		1.30				
	Regional		0.64		0.64		1.10		1.10				
Denmark	National Network		0.26		0.26		0.26		0.26				
Estonia	All		0.78		0.78		1.70		1.70				
Finland	All		0.35		0.35		0.76		0.76				
France [a)]	A (hi traffic peri-urb)	5.14	0.85	0.91	6.90	5.14	1.44	0.32	6.58				
	B (med traffic peri-urb)	1.48	0.85	0.56	2.89	1.48	1.44	0.20	2.92				
	C/C* (hi traffic intercity)	0.77	0.85	0.56	2.18	0.77	1.44	0.20	2.21				
	D/D* (med traffic intercity)	0.05	0.84	0.56	1.45	0.05	1.43	0.20	1.48				
	E (all other)	0.01	0.84	0.56	1.40	0.01	1.43	0.20	1.43				
	N1 (hi traffic hi speed)									12.42	2.48	0.11	14.89
	N2 (med traffic hi speed)									5.55	2.48	0.07	8.03
	N3 (lo traffic hi speed)									2.84	2.48	0.07	5.32
	N4 (East Eur hi speed)									2.54	2.48	0.07	5.02
Germany	F+ (long dist)										17.47		17.47
	F1 (long dist)						7.42		7.42		8.90		8.90
	F2 (long dist)						4.70		4.70				
	F3 (long dist)						4.18		4.18				
	F4 (long dist)						3.99		3.99				
	F5 (long dist)						3.07		3.07				
	F6 (long dist)						3.60		3.60				
	Z1 (feeder)		4.10		4.10		4.10		4.10				
	Z2 (feeder)		4.25		4.25		4.25		4.25				
	S1 (urban rapid)		2.62		2.62								
	S2 (urban rapid)		3.53		3.53								

	Line Category	Calculated access charge based on network statement (EUR/train-km)											
		Passenger											
		Regional, local, suburban				Intercity				High speed			
		Res.	Usage	Stat. stops	Total	Res.	Usage	Stat. stops	Total	Res.	Usage	Stat. stops	Total
	S3 (urban rapid)		4.24		4.24								
Hungary	Category I		2.70	3.30	6.01		2.43	0.60	3.03				
	Category II		1.52	1.41	2.93		1.60	0.25	1.85				
	Category III		0.52	0.17	0.69		0.63	0.10	0.73				
Italy [a)]	Line specific		2.49		2.49		2.90		2.90		3.32		3.32
Latvia	All		3.98		3.98		3.88		3.88				
Lithuania	All		2.77		2.77		4.60		4.60				
Netherlands	All		0.95	0.50	1.45		1.50	0.11	1.62				
Poland	0 to 40		0.68		0.96		0.96		0.96				
	40 to 60												
	60 to 80												
	80 to 100												
	100 to 120												
	>120												
Portugal	GH1 (suburban)		1.37		1.37		1.37		1.37				
	GH2 (suburban)		1.20		1.20		1.20		1.20				
	GH3 (suburban)		2.16		2.16		2.16		2.16				
	GH4		1.30		1.30		1.30		1.30				
	GH5 (suburban)		1.37		1.37		1.37		1.37				
	GH6 (electrified)		1.38		1.38		1.38		1.38				
	GH7 (elect., mostly fr.)		1.04		1.04		1.04		1.04				
	GH8 (non elect., lo density)		1.76		1.76		1.76		1.76				
	Non-elect., RES block		1.31		1.31		1.31		1.31				
Romania	All		2.52		2.52		2.52		2.52				
Slovak Republic	Category I		5.26		5.26		1.95		1.95				
	Category II		5.21		5.21		1.88		1.88				
	Category III		5.04		5.04		1.67		1.67				
Slovenia	Mean Lines (1.0 weight)		2.34		2.34		2.23		2.23				
	Regional Lines (0.7 weight)		1.64		1.64		1.56		1.56				
Spain [a)]	A1 Madrid/Barcelona, Cordoba/Malaga, Madrid/Valladolid	1.10	0.79		1.89	1.10	0.79		1.89	2.39	0.91		3.30
	A2 Madrid/Sevilla, Tramo, LaSagra/Toledo, Zaragossa/Huesca	1.50	0.72		1.77	1.05	0.72		1.77	2.19	0.83		3.02
	B1 Corredor Mediterraneo	0.21	0.06		0.27	0.21	0.06		0.27				

	Line Category	Calculated access charge based on network statement (EUR/train-km)											
		Passenger											
		Regional, local, suburban				Intercity				High speed			
		Res.	Usage	Stat. stops	Total	Res.	Usage	Stat. stops	Total	Res.	Usage	Stat. stops	Total
	C1 Rest of system	0.21	0.06		0.27	0.21	0.06		0.27				
Sweden	All		0.41		0.41		0.77		0.77				
United Kingdom a)	All	0.11	0.77		0.89	0.11	2.25		2.37				
Croatia	Class 1		0.06		0.06		0.15		0.15				
	Class 2		0.05		0.05		0.11		0.11				
	Class 3		0.02		0.02		0.04		0.04				
	Class 4		0.02		0.02		0.06		0.06				
	Class 5		0.02		0.02		0.05		0.05				
	Class 6		0.03		0.03		0.07		0.07				

(a) These countries have time of day access charges. Number shown are für "normal" time. Off-peak charges can be half or less of "normal" and Peak charges can be twice or three times "normal".

Source: International Transport Forum: Charges of the Use of Rail Infrastructure, 2008, Table 5.

Annex H. Excel tables with country-specific unit values

The Excel annex contains country-specific estimates for the following cost categories:

Road transport:

- Air pollution costs
- Noise costs
- Congestion costs
- Infrastructure costs

Rail transport:

- Air pollution costs
- Noise costs.

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